HIGH FREQUENCY ELECTRONICS

LoRa Networks Enabling Industrial IoT Applications

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Ideas for Today's Engineers: Analog · Digital · RF · Microwave · MM-Wave · Lightwave

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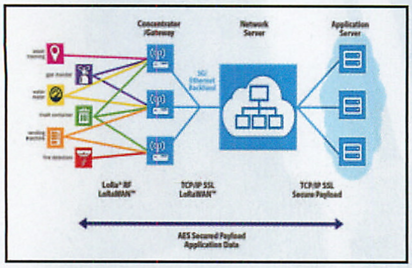
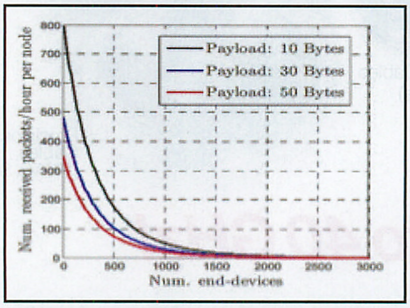
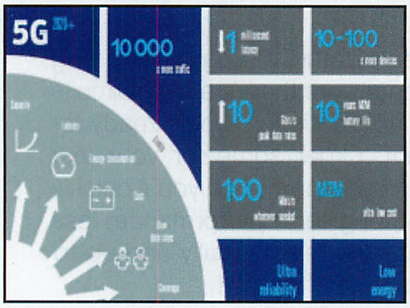
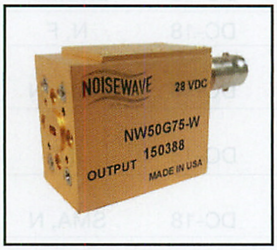
JANUARY2018
Vol. 17 No.1

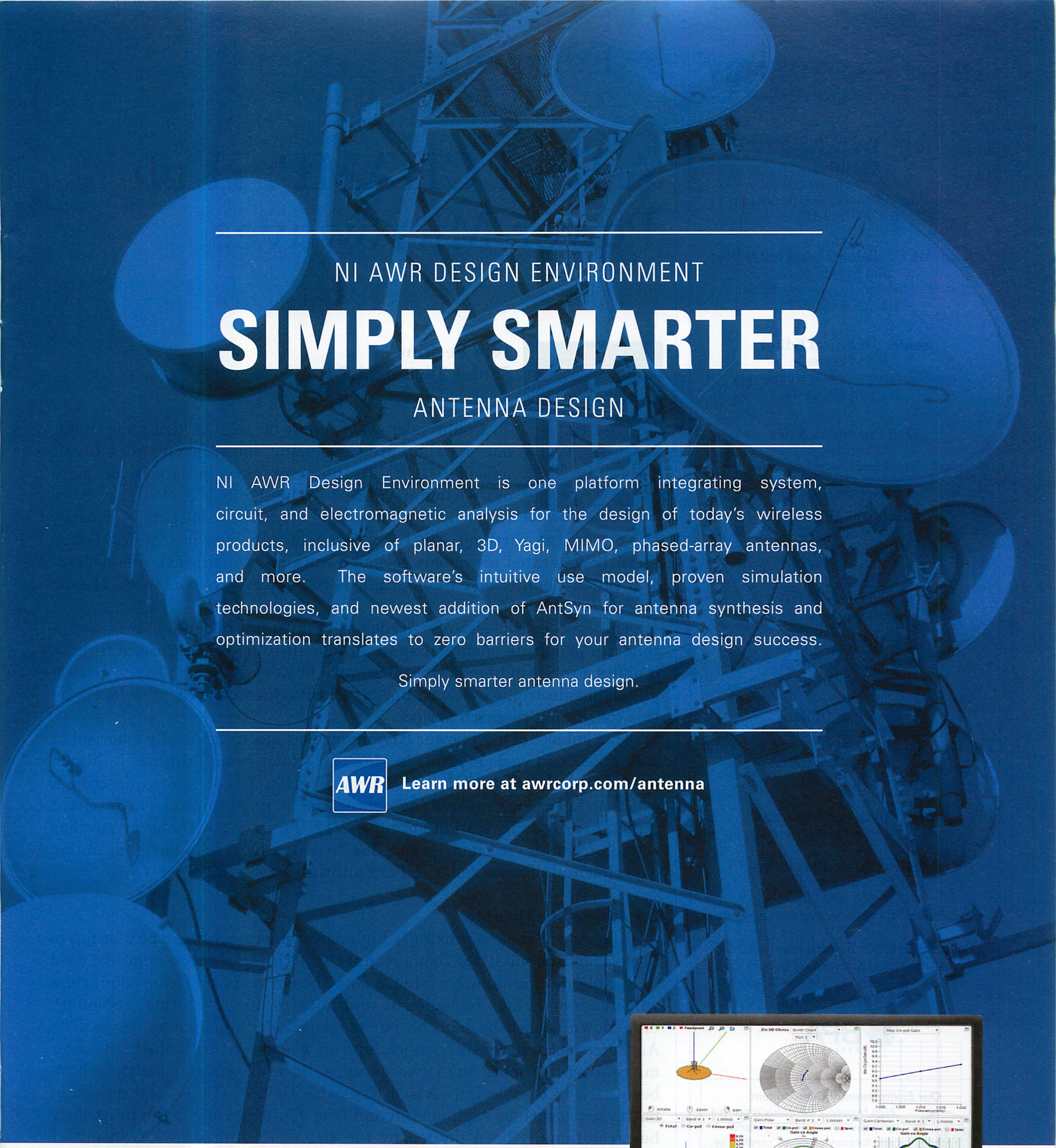
HIGH FREQUENCY ELECTRONICS

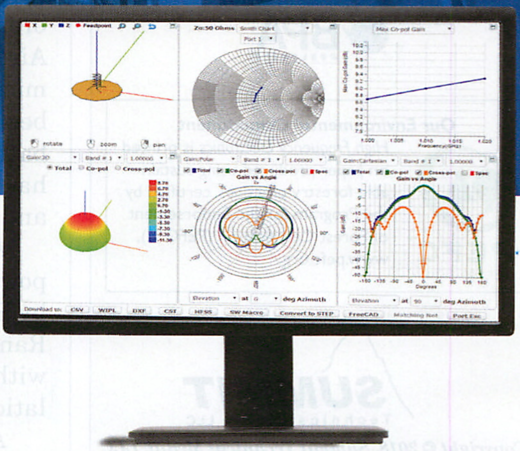












AntSyn | Antenna Synthesis

HIGH FREQUENCY
ELECTRONICS

Vol. 16 No. 1 January 2018

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One Hardy Road, Ste. 203
PO Box 10621
Bedford, NH 03110

Also Published Online at
www.highfrequencyelectronics.com

Subscription Services
Sue Ackerman
Tel: 651-292-0629
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SUMMIT
Technical Media LLC

Editorial

A Real CHAMP: High Power Microwaves

Tom Perkins
Senior Technical Editor

Could microwaves play a role in defeating rogue nations that are developing intercontinental ballistic missiles (ICBMs) that can carry weapons of mass destruction (WMDs)? The United States Air Force Research Laboratory (AFRL), Directed Energy Directorate at Kirtland Air Force Base in Albuquerque, New Mexico, recently reiterated previously revealed work on a microwave weapon system called Counter-electronics High Power Microwave Advanced Missile Project (CHAMP).

The system consists of missiles with a greater-than-500-mile range that can penetrate enemy airspace at low altitude. When close to targets, it emits a series of high power microwave pulses with capability to disrupt or disable electronic systems. Boeing and Raytheon are the developers on this continuing research project.

This subject of high power RF/microwaves has tangentially emerged at times before in various forms in *HFE*, for example; an Editorial in March 2015 titled *Far Field Wireless Energy Transfer.* Other stories describe a construction crane rendered inoperative due to its boom that was resonant with a nearby radio station antenna (*HFE* January 2014) and mysterious sounds from an electronic organ due to a nearby mechanically scanning experimental defense radar (*HFE* Editorial October 2015).

Capability to Disable

Knowing that close proximity high power microwaves can be disruptive to electronic circuits, it is thought that this CHAMP weapon might be used to disable missile launch systems. One theory holds that semiconductors will undergo serious breakdowns and failures due to thermal secondary breakdown caused by high output transient electromagnetic waves. The Air Force has apparently been working on weaponization using high power microwaves for more than two decades. Several types of emitters have been used to disable Improvised Explosive Devices (IEDs) and drones in battle zones such as Afghanistan and Iraq. Quite obviously the technology has traditionally been limited by the size of the microwave transmitter and its associated prime power source.

AFRL began work on CHAMP in 2009. The lab eventually fitted a high-power microwave emitter into an air-launched cruise missile (ALCM) built by Boeing. In 2012 a missile was launched over the Utah Test and Training Range from a B-52 bomber. Mock-ups of building structures were outfitted with communications and computer systems that simulated enemy installations.

According to NBC news, CHAMP budget documents indicate that many of the targets involved "representative weapons of mass destruction

(WMD) production equipment" found in Iran and North Korea. The technology made computers turn dark and even the cameras monitoring the test failed. "It was as close to the real thing as we could get," Keith Coleman, CHAMP program manager for Boeing, said after the test. "It absolutely did exactly what we thought it was going to do," said Mary Lou Robinson, head of weapons development at Kirtland. "We had several different target classes in those facilities, and we predicted with almost 100 percent accuracy ... which systems were going to be affected, which systems failed, and how." She did add that in order to disable a missile or launcher's electronics, CHAMP would have to get "close" to the target. Considering that radiated power decreases by ¼ (-6 dB) each time distance doubles, plus atmospheric microwave absorption, the reason for "close" is obvious. Note, for a starting point, the free-space attenuation at X-band over 10 feet is about 62 dB.

The 2012 test, apparently the only one declassified by the Pentagon, has been followed by additional tests and various experiments to advance the microwave technology. A new power source is reported to have been incorporated, turning the microwave weapon into what the Air Force calls "Super CHAMP."

In May 2015, the Air Force nominated the Lockheed Martin AGM-158 Joint Air-to-Surface Standoff Missile-Extended Range (JASSM-ER) as the optimal air vehicle to carry the CHAMP payload. According to a January 2016 AFRL document, the low-flying missile is now "capable of flying into a contested area and disabling an adversary's electronic systems." Speaking in February 2016, Air Combat Command chief Gen. Herbert "Hawk" Carlisle said that a number of high-power microwave units were being kept as "weapons to use in a contingency."

Application and Consequences of the Technology

Also reported, in 2013 Raytheon demonstrated a ground-based air defense high-power microwave system derived from CHAMP. It disabled electronics on small unmanned air vehicles (UAVs). It resembles the active denial system non-lethal crowd control device, including a reflector and steering mirror. It is integrated with radar automatic tracking. The first prototype is reported to be 6 meters in length; however, efforts to provide the same capability in half that size have been reported.

We might speculate that traveling wave tubes, (TWTs), GaN,

(Continued on page 8)

Meetings and Events

2018 IEEE Radio Wireless Symposium
Jan 15 - 18, 2018
Garden Grove, CA
radiowirelessweek.org

IEEE Wireless and Microwave Technology Conference (WAMICON)
April 3 – 4, 2018
wamicon.org

IEEE MTT-S International Conference on Microwaves for Intelligent Mobility 2018 (ICMIM 2018)
April 16 – 17, 2018
Munich
http://icmim-ieee.org/

IMS 2018
June 10 – 15, 2018
Philadelphia
https://ims2018.org/

RFIC 2018
June 10 – 12, 2018
Philadelphia
https://rfic-ieee.org/

2018 43rd International Conference on Infrared, Millimeter and Terahertz Waves (IRMMW THz-2018)
September 9 – 14, 2018
Nagoya, Japan
http://www.irmmw-thz2018.org/

Company-Sponsored Training & Tools

Analog Devices
Training, tutorials and seminars.
http://www.analog.com/en/training-tutorials-seminars/resources/index.html

NI AWR
On-site and online training, and open training courses on design software.
http://www.awrcorp.com/news/trainings

National Instruments
LabVIEW Core 1
Online
http://sine.ni.com/tacs/app/fp/p/ap/ov/pg/1/
LabVIEW Core 2
Online
http://sine.ni.com/tacs/app/fp/p/ap/ov/pg/1/
Object-Oriented Design and Programming in LabVIEW
Online
http://sine.ni.com/tacs/app/fp/p/ap/ov/pg/1/
Free, online LabVIEW training for students and teachers.
http://sine.ni.com/nievents/app/results/p/country/us/type/webcasts/

Upcoming Events: Women in Engineering

Women in Engineering National Leadership Conference
May 21 - 22, 2018
San Jose
http://wie.ieee.org/events/

(Continued from page 7)

advances in active electronic scanned arrays (AESAs), and global positioning satellite (GPS) guidance may play a role in miniaturization efforts. Also, advances in lightweight switching power supplies might be leveraged. If the systems are expendable, devices can perhaps be stressed well beyond their normal operating limits to achieve the desired result.

There are obvious challenges to getting these high-power radiator devices near a selected target. However the uncertainty thrust on a totalitarian nation will hopefully prompt concern for the consequences of aggressive behavior. This is one open microwave oven you don't want to be near.

Advanced MIMO Boosts 4G Performance, Helps Operators Prepare 5G

Recent field test results in live commercial networks prove that 4x4 MIMO can effectively improve network performance and user experience, and the device ecosystem is rapidly developing to support 4x4 MIMO, concludes Strategy Analytics in the report "4x4 MIMO Boosts 4G and Gives Consumers a Taste of the Gigabit Experience." The report from the Strategy Analytics Networks and Service Platforms, and RF & Wireless Components advisory services, predicts **4x4 MIMO will be gaining momentum in 4G infrastructure market and becoming a mainstream configuration of flagship smartphones.**

Guang Yang, Director of Wireless Networks and Services, said "field test results prove that 4x4 MIMO can be an efficient tool for mobile operators to improve network capacity and user experience to meet fast growing mobile data demands. Because 5G coverage will be limited in its early phase, customer's seamless mobile broadband experience will still rely on the underlay 4G network. The performance of the underlay 4G network will be important for the success of early 5G deployment. "

Christopher Taylor, Director of the RF & Wireless Components advisory service, **added "Gigabit LTE using 4x4 DL MIMO is at the leading edge today. The ecosystem is developing rapidly, with new phone models supporting 4x4 MIMO arriving on retail shelves every month. More phone chip suppliers will soon enter the market with LTE radio modems that support 4x4 DL MIMO** as well as advanced carrier aggregation with five CCs, LAA / LTE-U and eventually millimeter wave 5G. This will benefit the entire ecosystem from operators to consumers with more availability, lower prices, and new services."

—Strategy Analytics
strategyanalytics.com

Dynamic End-to-End Network Slicing Key to 5G Profitability

According to the Strategy Analytics Service Provider Strategies (SPS) report, Communications Service Providers (CSPs) can grow revenues and enhance profits with dynamic end-to-end (E2E) network slicing in 5G. Digging into examples from BT, Verizon and others, Strategy Analytics examines early stage developments and delivers a call to action for more collaboration to address both business and technical challenges to deliver on the promise of network slicing for 5G Return on Investment (RoI).

Key findings from the report:

Network slicing is a mechanism that will allow CSPs to dynamically allocate network resources in ways that will maximize customer value so that 5G can serve new purposes, adapt to specific needs and drive revenue opportunities. With dynamic E2E network slicing, the industry can begin to move to a model where services expand and contract their use of network resources as traffic demands.

5G network slicing is expected to deliver service agility, enhanced security and "just fit" services for enterprises, among other benefits. In particular, network slicing will enable CSPs to offer Network as a Service (NaaS), with new Mobile Virtual Network Operator (MVNO) or partner models for verticals and specific segments/use cases.

Susan Welsh de Grimaldo, Director, Service Provider Strategies, Strategy Analytics recommends: "We challenge the mobile industry with a 'Call to Action' in 2018 to deliver on the promise of network slicing as we move closer to commercial 5G deployments:

- increase enterprise, MVNO and vertical engagement in business case development and requirements for 5G network slicing;
- learn through further trials to feed into R&D and business model development;
- work on process and organizational changes that will be needed to implement 5G network slicing;
- develop common definitions and parameters of slices across operators;
- work on incorporating machine learning, analytics and artificial intelligence (AI) into the development of network slicing."

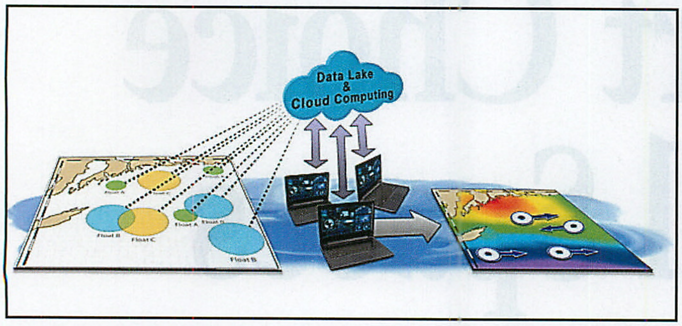
Akbar Rahman, Sr. Principal Engineer, InterDigital, as a sponsor of the report and participant in the related webinar, explains that to support dynamic slicing, **"some business relationship has to be available...the operator might have the most dynamic network slicing system available, but if they have no way to advertise the APIs, no way to charge for it...I believe the mobile operators will start becoming like Amazon or Google where they offer APIs and basically a credit card or some other electronic charging system... "**

Dr. Geng Wu, Intel's Chief Technologist and Director of Wireless Standards and Advanced Technology observes: "The new set of challenges and also the opportunity is how you actually transform the network with technology to serve the many new sets of applications, new industries and actually enable the next round of innovation."

Caroline Chan, VP and GM, 5G Infrastructure Division, Network Platform Group, Intel adds: "For 5G, you have to expand your ecosystem…start talking to folks you don't normally talk to, you understand who actually pays the bill, who is willing to adopt your technology."

—Strategy Analytics
strategyanalytics.com

In the News



Ocean of Things Aims to Expand Maritime Awareness across Open Seas

The internet of things connects an ever-growing number of smart devices for up-to-the-minute monitoring and tracking of many common events. Head out to most parts of the open ocean, however, and no such capability exists for real-time monitoring of maritime activity.

DARPA today announced its **Ocean of Things program, which seeks to enable persistent maritime situational awareness over large ocean areas by deploying thousands of small, low-cost floats that could form a distributed sensor network. Each smart float would contain a suite of commercially available sensors to collect environmental data—such as ocean temperature, sea state, and location—as well as activity data about commercial vessels, aircraft, and even maritime mammals moving through the area. The floats would transmit data periodically via satellite to a cloud network for storage and real-time analysis.**

"The goal of the program is to increase maritime awareness in a cost-effective way," said **John Waterston**, program manager in DARPA's Strategic Technology Office (STO). "It would be cost-prohibitive to use existing platforms to continuously monitor vast regions of the ocean. By coupling powerful analytical tools with commercial sensor technology, we plan to create floating sensor networks that significantly expand maritime awareness at a fraction of the cost of current approaches."

The technical challenge for Ocean of Things lies in two key areas: float development and data analytics.

Under float development, proposers must **design an intelligent float to house a passive sensor suite that can survive in harsh maritime environments. Each float would report information from its surroundings for at least one year before safely scuttling itself in the deep ocean. The floats will be required to be made of environmentally safe materials, pose no danger to vessels, and comply with all federal laws, regulations, and executive orders related to protection of marine life.**

The data analytics portion of the Ocean of Things program will require proposers to develop cloud-based software and analytic techniques to process the floats' reported data. This effort includes dynamic display of float locations, health, and mission performance; processing of environmental data for oceanographic and meteorological models; developing algorithms to automatically detect, track, and identify nearby vessels; and identification of new indicators of maritime activity.

—DARPA

DARPA's Software Defined Radio Hackfest Creates Solutions for Spectrum Challenges

The DARPA Bay Area Software Defined Radio (SDR) Hackfest came to a close on Friday, November 17 at the NASA Ames Conference Center in Moffett Field, CA. During the weeklong event, **over 150 members of the SDR community came together to discuss, innovate, and ideate around the future of software radio technology and its potential to address challenging communications issues that are emerging due to the increasingly congested electromagnetic (EM) spectrum and the proliferation of wireless-enabled devices.**

"The DARPA SDR Hackfest was created to engage a growing community of SDR developers and enthusiasts from a diverse range of backgrounds and I believe we accomplished that mission," said **Tom Rondeau**, a program manager in DARPA's Microsystems Technology Office (MTO), who led the event. "The Hackfest provided community members with a place to interact with experts and explore new ideas around the potential for the technology, and our speaker series at the event challenged attendees to contemplate everything from the trajectory of the UAV industry to the challenges we must address to ensure the free and open sharing of software."

Throughout the Hackfest, eight pre-qualified teams from academia, industry, and the hacker- and makerspace-communities worked together to develop solutions to specific "Hackfest Missions." Presented to the teams on

In the News

the first day of the event, **the three Missions amounted to problem sets designed to examine how SDR could be used to solve communications, computing, and control challenges at the still-uncharted intersections of cyber and physical technologies. Each Mission focused on the communications link between ground stations and unmanned aerial vehicles (UAVs) or drones. These links are susceptible to breaking due to interference, EM congestion, or other communications issues. In developing the Missions, DARPA's Hackfest organizers consulted with groups of military operators to ensure that various real-world scenarios involving radio and UAV technologies would be included. As such, it is possible that some of the solutions to these communications challenges that emerged during the event could progress toward real-work applications.**

"The future use of drones–whether on land, in water, or in the air–will require far more coordination of the communications channels among all involved users. Trading off resource constraints of spectrum, processing power, and security risks, the Hackfest challenged teams to think through the whole stack from the application layer down to the physical," said Rondeau.

Hackfest teams were asked to tackle one of the three Missions throughout the week. The goal of Mission One was to find a way to enable communications between a ground station and a UAV with a blocked or obstructed communication pathway. Teams were tasked with using a second UAV to create a relay link for the ground station to the obstructed UAV. This first Mission simulated real-world circumstances in which communication links can be denied for any number of reasons–from physical barriers to deliberate or accidental EM interference.

Two of the participating teams took on Mission One, leveraging a number of open-source technologies to extend communications between the ground station and the obstructed UAV.

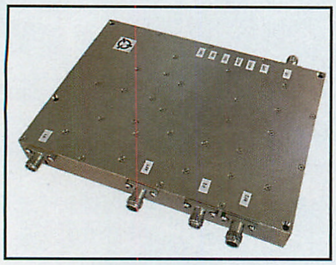
"YeS DR, a team of cybersecurity experts from Parsons, added an authentication method to their solution that helped certify who communication packets were intended for–a unique approach that played to their strengths as cyber experts," said Rondeau. "Team DROGON also attempted Mission One. Bringing experts from Raytheon BBN Technologies and SSCI to the Hackfest, the team took full advantage of the provided code by using the Linux kernel's BATMAN (Better Approach to Mobile Adhoc Networking)–a routing protocol that intelligently distributes information across a network—to rethink the mission as a network of nodes instead of separate ground stations and UAVs that were given different tasks."

In Mission Two, teams were asked to show that control of a moving UAV could be repeatedly transferred between multiple ground stations.

This Mission was designed to mirror scenarios where detailed flight work is required but a pilot's visibility is degraded or limited due to, say, environmental conditions or changes in geography. This type of scenario is seen in civilian or disaster response operations where drones are employed.

To jointly address Mission Two and One, one team sought to create a solution that considered every node in their system, whether a ground station or UAV, to be a network.

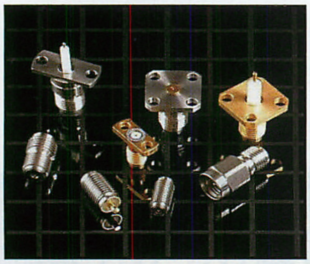
—DARPA



Block Frequency Converters

Norden Millimeter announced continued expansion of its growing line of block frequency converters converting 18-26.5, 26.5-40, 26-50, 40-70, and 60-90 GHz bands into the 2 - 18 GHz band. These converters extend the frequency range of existing systems with 18 GHz capability. Norden offers both down and up converter versions for each of these bands. They can have variable gain, .03 - 18GHz bypass paths, and common IF input/output. Shown is an 18-40 GHz downconverter presently in production with 14.4 GHz LO Frequency and 0.5 to 18 GHz converter bypass.

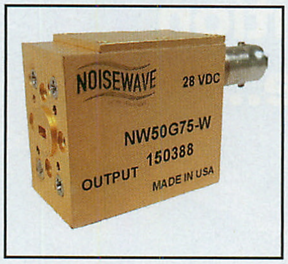
Norden Millimeter
nordengroup.com



Precision Receptacles

SGMC Microwave offers an extensive line of Precision Receptacles. 1.0mm, 1.85mm, 2.4mm, 2.92mm, 3.5mm, N, SMA, & SSMA are some of the various interfaces we have readily available. Configurations include, but are not limited to Threaded Barrel (spark plug), 2 & 4 hole flange, PCB Mount (pin or tab), and Extended Pin & Dielectric. Special/Custom Design service & modifications are also available. The name to count on for Quality, Performance, and Reliability!

SGMC Microwave
sgmcmicrowave.com



Noise Sources

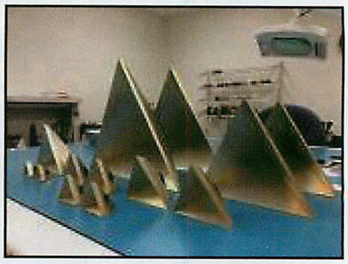
NoiseWave released a line of precision millimeter waveguide noise sources. The NW-W series of waveguide noise sources covers all major millimeter waveguide bands with high output, excellent flatness and ripple-free response. Designed for both built-in test and laboratory applications, these units can also replace outdated gas tube noise sources. Models are available up to 110GHz (W-band) with output ENR from 6dB to 50dB. Applications include noise figure measurement, millimeter wave radiometers, automotive radar as well as research and development in high frequency broadband wireless applications.

Noisewave
noisewave.com

Cable Assemblies

Amphenol RF is pleased to introduce a line of SMA fixed length cable assemblies on LMR-195 and LMR-240 cables. This full Amphenol solution combines precision machined Amphenol RF SMA connectors with high performing LMR cables developed by Times Microwave, an Amphenol company. These pre-configured cable assemblies are designed to offer a lower loss option with superior electrical performance to standard cables.

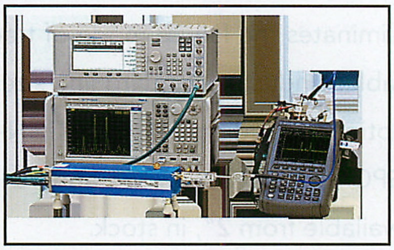
Amphenol RF
amphenolrf.com



Corner Reflectors

SAGE Millimeter offers standard and custom trihedral corner reflectors for radar applications. They feature a rugged aluminum construction with a gold chemical film finish. The trihedral reflector simulates a radar target precisely and is widely used for radar system calibration. With a ¼-20 threaded hole for a built in mounting bracket, the reflector can be mounted onto a tripod for rapid system setups. SAGE Millimeter offers many standard trihedral corner reflectors from 1.8" to 16".

SAGE Millimeter
sagemillimeter.com

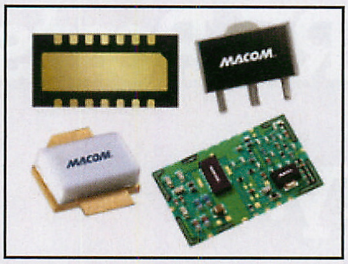


IMD

OML introduced millimeter wave (mm-wave) intermodulation distortion (IMD) measurements to target emerging gigabit applications such as WirelessHD, WiGig, 802.11ad and E-band point-to-point radios. In these applications, the linearity of amplifiers and transceivers can adversely affect bit error rate, especially those involving higher order modulation. Due to waveguide constraints, IMD has been nearly non-existent on the millimeter wave frontier until now. For the first time, OML can thoroughly characterize mm-wave devices for S-parameters, gain compression, and IMD.

OML
omlinc.com

Featured Products



RF Power Products

MACOM offers a broad range of RF power semiconductor products as discrete devices, modules, and pallets designed to operate from DC to 6 GHz. Our high power transistors are ideal for civil avionics, communications, networks, radar, broadcast, industrial, scientific, and medical applications. MACOM has more than 60-year heritage of providing both standard and custom solutions using bipolar, MOSFET, and GaN technologies to meet customers' most demanding needs.

MACOM
macom.com

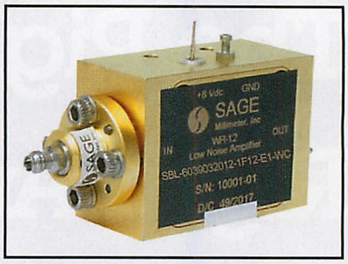
Frequency Synthesizer

The Luxyn frequency synthesizer features high-speed tuning from 50 MHz to 21 GHz in frequency steps as small as 0.001 Hz in a package that is only 4.0 × 3.6 × 0.9 in. and weighs only 15 oz. It is literally a fit for a wide range of applications, from broadband communications systems to test-and-measurement equipment. It provides spectrally pure output signals that can feed most measurement applications.

Micro Lambda Wireless
microlambdawireless.com

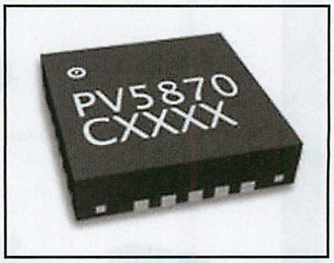
Power Amp

Model SBP-6039032012-1F12-E1-WC is an E band power amplifier with a typical small signal gain of 20 dB and a nominal P-1 dB of +12 dBm across the frequency range of 60 to 90



GHz. The DC power requirement for the amplifier is +8 VDC/250 mA. The input port configuration is a female 1 mm connector and the output is a WR-12 waveguide with a UG-387/U flange. Other port configurations are available under different model numbers.

SAGE Millimeter
sagemillimeter.com



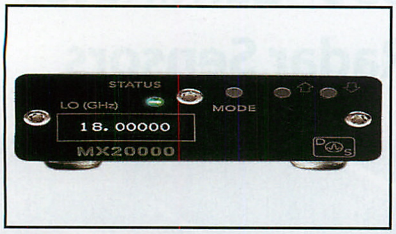
Demodulator

RFMW, Ltd. announced design and sales support for ParkerVision's direct conversion quadrature demodulator/modulator designed for communication systems requiring excellent linearity with the lowest possible power consumption. Drawing only 23mA from a 3V supply, the PV5870 consumes 1/5th to 1/10th the power of similar demodulators yet provides superior noise figure performance (a 6dB improvement over the nearest competitor). As a demodulator operating from 400 – 3600MHz, the PV5870 offers excellent amplitude and phase balance and very low DC offset.

RFMW
rfmw.com

Ku-Band Mixer

DS Instruments introduces the MX20000, a Ku-Band mixer with integrated programmable local oscillator. USB powered and controlled, the MX20000 with its low-phase-noise LO provides simple up and down-converting for applications

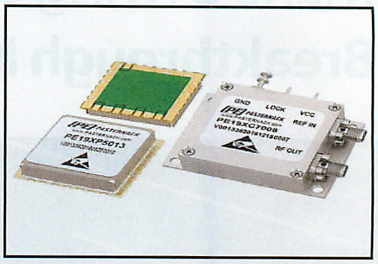


including satellite link testing. The USB serial port requires no drivers or API, only simple text commands.

DS Instruments
dsinstruments.com

PLOs

Pasternack's 20 new phase locked oscillator models are offered with popular fixed output frequencies of 50, 100, 500, 1000, 2000, 4000 and 6000 MHz. Typical performance for these PLOs includes excellent phase



noise of -105 dBc/Hz at 10 KHz offset, a buffered output power level of +7 dBm and low second harmonic and spurious suppression levels of -25 dBc and -70 dBc respectively. They require an external frequency reference of either 10 MHz or 100 MHz and feature a TTL lock detect output to signal an out-of-lock condition.

Pasternack
pasternack.com

40 GHz Power Sensor

The LadyBug LB5940A 1 MHz to 40 GHz RMS responding high accuracy power sensor is suitable for a wide variety of applications including manufacturing test, defense, SATCOM testing and general use. The sensor utilizes LadyBug's patented thermal stability processes to deliver stable, accurate measurements down to the sensors noise floor without zeroing. In addition to the included full featured software, the sensor features very strong programmatic support. A dual USB interface for uses of USBTMC or USB HID can control the sensor using standard SCPI commands. The sensor is kept in stock for immediate shipment.

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LoRa Networks Enabling Industrial IoT Applications

by Mark Miller

Industrial wireless sensor networks (IWSN) are a key enabling technology in allowing for a more autonomous industrial sensing, monitoring, and process automation environment; eliminating the need for specially designed industrial cabling for harsh environments. Early IWSN standards based in the IEEE 802.15.4 protocol such as WirelessHART (2007) and ISA100.11a (2009) guarantee a level of quality of service (QoS) with mesh networking and channel hopping over a 100m to 200m range.

LoRa is short for "Long Range" and requires end-devices that consume extremely low powers on the order of 10 to 25 mW.

The newly emerging Low Power Wide Area Network (LPWAN) fills a unique niche of connectivity that requires long battery life over a long range. LPWAN technology boasts a battery life of 5+ years per node with link distances that can range from 2 km to 3km. While WirelessHART and ISA100.11a are best used for low-latency time sensitive applications such as non-critical monitoring, alerting, and supervisory control applications below 100 ms, LPWAN technology can best serve automated meter reading, home/building automation, wireless alarm and security systems, irrigation systems, and other long range applications that do not require latency to be

Parameters	IWSN		Low Power Wide Area Network (LPWAN)			
	WirelessHART	ISO100.11a	LoRa	Sigfox	LTE-M1 (LTE Cat M1)	NB-IoT (LTE Cat NB1)
Operating Frequency	2.4 GHz	2.4 GHz	915 MHz for the U.S., 868 MHz for Europe, and 433 MHz for Asia	868 MHz, 902 MHz ISM	-	-
Maximum Range	~200m	~200m	2-15 km	up to 3 km	Verizon launch will allow for 2.4 million miles of square coverage in US	10-15 km
Throughput	250 kbps	250 kbps	0.3 kbps to 50 kbps	100 bps up, 600 bps down	Up to 1 Mbps	20 kbps to 144 kbps
Latency	10ms (direct to gateway), 30 ms (1 hop) to 50 ms	~ 100 ms	1-2 s (round-trip)	1–30s	10-15ms	1.6s to 10s
Bandwidth	3 MHz	5 MHz	125, 250, 500 kHz	Base station listening bandwidth: 200 kHz, 100 Hz UL channels; 600 Hz DL channels	1MHz to 1.4 MHz	180 kHz
Multiple Access DL Multiple Access UL	TDMA	TDMA with collision avoidance	FM Chirp Spread Spectrum (CSS) with FEC	ultra-narrowband (UNB) modulation/FHSS	-	-
Security	AES Encryption	AES Encryption	Public Key Infrastructure (PKI), AES Encryption, Trasport Layer Secutry (TLS)	HTTPS encrypted , Hard to Jam anyway to asynchronous nature	-	-
Battery life	several years	several years	10+ years	up to 20 years	5+ years	5+ years
Capacity (Number of connected devices)	30,000	unlimited	100,000+	-	-	55,000 devices per cell
Network Topology	star + point-to-point +Mesh	star + Mesh	star-of-stars topology	one-hop star topology	-	most topologies are star-based
Licensed or Unlicensed spectrum	Unliscensed	Unliscensed	Unliscensed	Unliscensed	Liscensed	Liscensed
Price	****	****	**	*	****	***

Table 1 • Overview of IWSNs and LPWANs.

deterministic. In the long run, Industrial connected wireless sensing, tracking, and control devices will approach 500 million in 2025 (from 35 million in 2017) where LPWAN technology including LoRa, Sigfox, LTE-M1, and NB-IoT will account for 25% of the connections by this time [1].

LoRa for Industrial Wireless Sensing

LPWAN variants such as Sigfox and NB-IoT leverage ultra-narrowband (UNB) technology, allowing for a lower transmit power with a high range as well as a high receiver sensitivity by effectively lessening its noise floor. As made evident in Table 1, this comes at the cost of packet size and throughput since there is not as much available bandwidth to transmit large amounts of information.

The wideband, high data rate LTE-M1 (also known as LTE Cat M1) offers up to 1.4 MHz of bandwidth but is a licensed technology whereas LoRa's open source networking platform enables a rich developer community for universities and startups to innovate. For instance, the University of Washington recently developed a wide-area backscatter system that can successfully achieve link distances of up to 2.8 km with a backscatter IC that costs 'less than a dime' consuming 9.25 µW of power with commodity LoRa hardware [2]. CableLabs has also created an open source LoRa server, LoRa App Server, and LoRa gateway bridge with a documentation and code repository in an effort to focus on open innovation as opposed to proprietary LPWAN solutions [4]. LoRa technology seems to be the primary contender in the LPWAN race for both public and private (industrial and enterprise) networks, this is due to the fact that it has enough bandwidth for most factory applications. According to ON World, LoRaWAN networks are currently deployed in 50+ countries and there is predicted to be nearly 500,000 LoRa networks installed worldwide by 2022.

A Brief LoRa Overview

LoRa is short for "Long Range" and requires end-devices that consume extremely low powers on the order of 10 to 25 mW. The physical (PHY) layer leverages a FM chirp spread spectrum (CSS) radio modulation technique with forward error correction (FEC) and a medium access control (MAC) layer with the LoRa wide-area-network (LoRaWAN) protocol. While the network can transmit and receive at many frequencies between 150 MHz and 1 GHz, LoRa technology operates in the 915-MHz band in

LoRa Networks

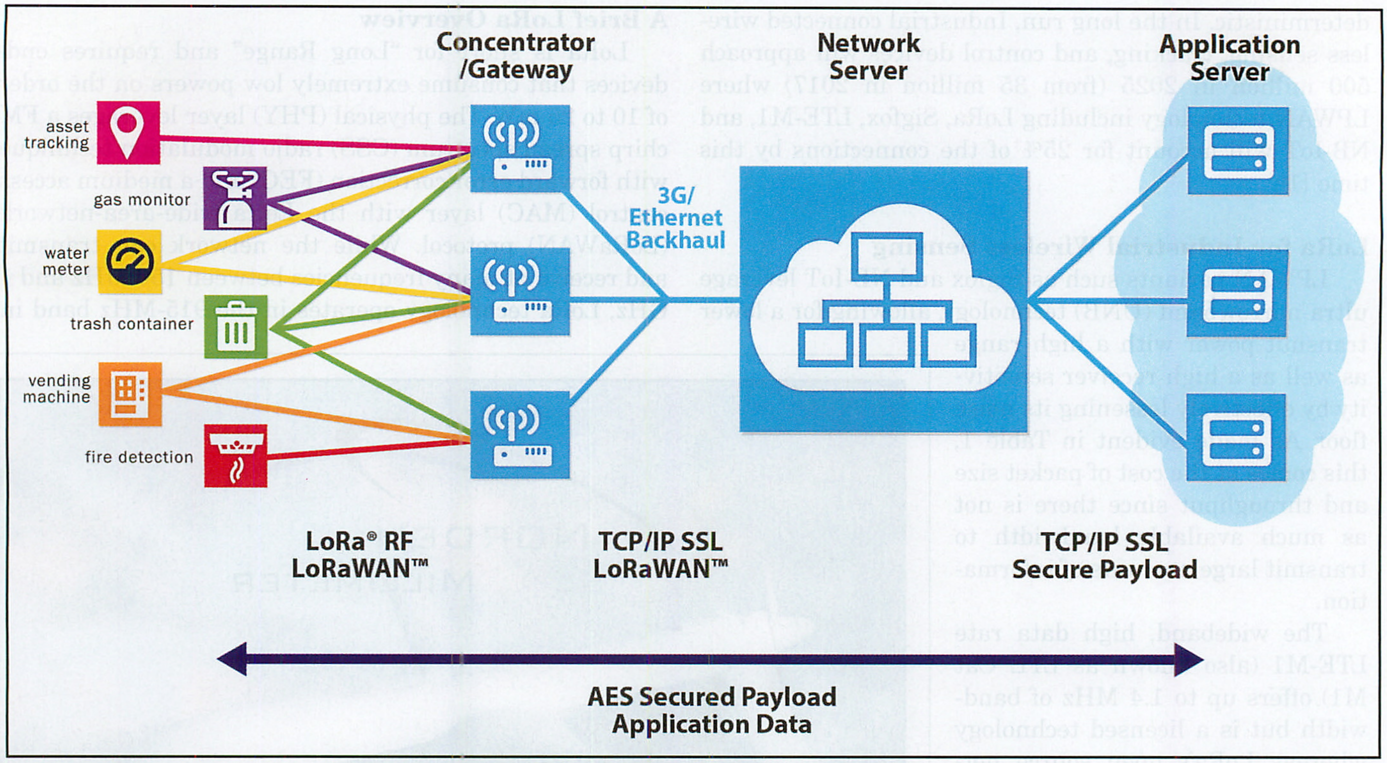

Figure 1 • LoRaWAN network diagram. Source: http://www.semtech.com/wireless-rf/internet-of-things/what-is-lora/

the United States, the 868-MHz band in Europe, and the 433-MHz band in Asia – all are unlicensed industrial, scientific, and medical (ISM) bands. With a maximum throughput of 50 kbps with channel aggregation, LoRa transceivers from Semtech (e.g.: the SX1272) can operate with three programmable bandwidths: 125 kHz, 250 kHz, and 500 kHz.

PHY LoRa Layer

The spread spectrum in LoRa is established by generating a chirp signal – a signal where the frequency increases – that continuously varies in frequency. The benefit of leveraging this is the timing of frequency offsets between the transmitter and receiver are identical thereby limiting the data rate for an increase in receiver sensitivity and ultimately, the range of the LPWAN. Additionally, the spread spectrum inherently has immunity to multipath and fading. The time-on-air or latency can be modified through adjustable parameters include payload size, data rate, error correction coding, range, spreading factor (SF), and bandwidth (BW). Within LoRa, there is a trade-off between the occupied bandwidth (which directly correlates to data rate) and the sensitivity of the receiver as shown in equation below [3].

$$S = -174 + 10\log_{10} BW + NF + SNR \qquad \text{Eqn. 1}$$

Where S is the sensitivity of the radio receiver, BW is the receiver bandwidth, NF is the receiver noise figure, SNR is the signal-to-noise ratio. A design engineer leveraging a LoRa transceiver will only have control over the NF and SNR parameters in order to optimize the sensitivity of the receiver. Similarly, there is a trade-off between the SF and the link range; the higher the SF, the longer the range, and the slower the data rate. Since LoRa hardware operates in the unlicensed spectrum, QoS cannot be guaranteed and therefore frequency agility schemes (frequency hopping) are often employed on each transmission to mitigate external interference. Still, this can increase the interference and packet error rate (PER) since one of two scenarios often occur: the transmitter/receiver jumping to an already occupied channel or having another end-device hop to the channel during a target transmission.

MAC Layer

There are primarily two MAC layer options for LoRa networks: LoRaWAN and Symphony Link. LoRaWAN is a public network protocol managed by the LoRa alliance and is most commonly used in noncommercial applications whereas Symphony link was specifically designed by Link Labs to better fit industrial and enterprise applications. The non-proprietary nature of LoRaWAN has allowed for a more rapid proliferation of this MAC protocol while Symphony link was developed by Link Labs in

Class	Parameter optimized	Bidirectional	Unicast	Multicast	Small Payloads	Long Intervals	Differentiating Factor
Class A	Battery powered	*	*		*	*	End-device initiates transmission at any time, server constantly listening
Class B	Low Latency	*	*	*	*	*	Server can initiate transmission in slotted intervals
Class C	No Latency	*	*	*	*		Server intiates transmission at any time, end-device constantly listening

Table 2 • LoRaWAN Classes [7].

order to exploit the benefits of the PHY LoRa layer while improving on some of the limitations of LoRaWAN.

LoRaWAN

As shown in Figure 1, the LoRaWAN is typically laid out in the star-of-stars topology where gateways (aka: access point or base station) relay messages between end-devices and the network server. End-devices relay information to the gateway(s) over a single wireless hop. Gateways, in turn, send information via cellular or hard-wired Ethernet backhaul to the network server. Finally, the information is processed through an application server that handles subscription and data management (e.g.: firmware upgrades and mobile network operator (MNO) subscription). The application server is typically deployed through the cloud where the messages are encrypted/decrypted.

While communication between server and nodes is bidirectional, uplinked data transmissions from the end-device to the gateway is the default option. As shown in Table 2, there are three types of end-device classes: A, B, and C. All three classes can be utilized in the same network and each end-device can switch from one class to another but Class A must be implemented on all end-devices. Both Class B and Class C are compatible with Class A, but Class C devices cannot implement Class B [6]. The LoRaWAN topology takes advantage of the CSS modulation scheme by managing the data rate and RF output for each end device through an adaptive data rate (ADR) scheme [8].

Symphony Link

Instead of leveraging the cloud heavily – a parameter that can lead to a security issue for industrial networks – Symphony Link completes the MAC process on the gateway so that it can deployed as a stand-alone system in a plant without the need for the internet. Moreover, this MAC layer uses repeaters to proxy traffic between nodes and expand the range of the network instead of outdoor gateway access points. There are no device classes since this system uses a synchronous scheme to allow for the higher data reliability and lower latencies that are necessary for IIoT applications.

Symphony Link vs. LoRaWAN for IIoT

The use of the unlicensed ISM bands can be a double-edged sword since neighboring LoRaWAN networks can cause channel interference where a LoRa modem is decoding all packets in the vicinity – ultimately negatively impacting the PER of a system. Symphony Link is partnered with licensed spectrum partners to allow for dedicated spectrum for safety critical industrial applications. LoRaWAN-based networks have shown success in periodic messaging applications where there is a certain threshold of delay between message transmissions. For instance, in smart street lighting applications, lighting

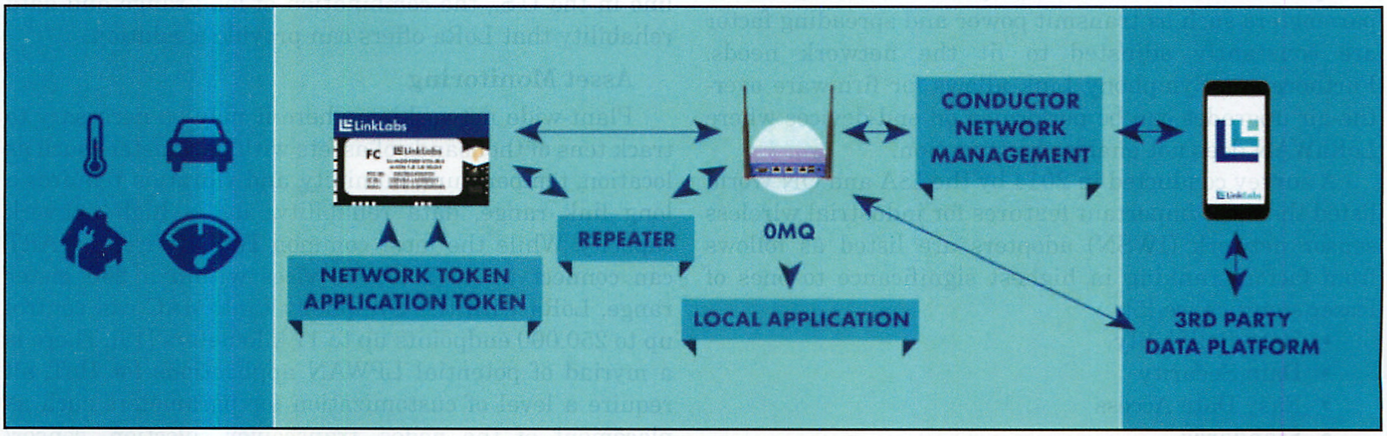

Figure 3 • Symphony Link network diagram [9].

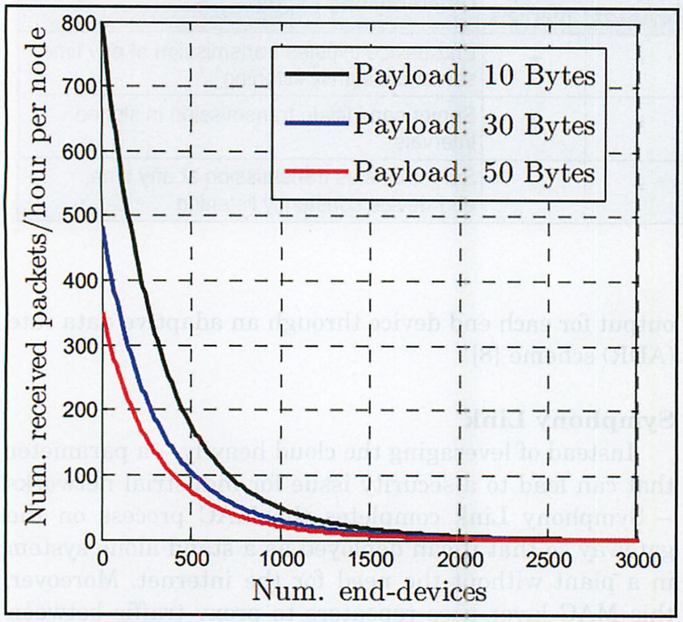

Figure 4 • Graph illustrating impact of an increase in channel capacity with the number of packets received per hour when end-devices attempt to transmit [6].

elements are triggered for ON/OFF switching or dimming functions in events such as a sunrise or sunset – events that are widely spaced out in time.

The duty cycle, or maximum percent of time an end-device can occupy a channel, can also be a major limitation in LoRaWAN technologies. While the FCC does not provide a duty cycle limitation for the United States 915-MHz ISM band, the European Commission mandates a maximum of 1% for end-devices in the 868-MHz band. Symphony Link does not have duty cycle limitations and uses proprietary frequency agility schemes to optimize data rates and time-on-air. The architecture is more streamlined as the complicated key management that comes with hundreds of thousands of devices is handled. The protocol also comes with a dynamic data rate where parameters such as transmit power and spreading factor are constantly adjusted to fit the network needs. Furthermore, Symphony Link allows for firmware over-the-air upgrades can be performed on end-devices where LoRaWAN does not enable that function.

A survey conducted in 2014 by the ISA and ON World listed the most important features for industrial wireless sensor network (IWSN) adopters are listed as follows from factors ranking in highest significance to ones of lesser significance [5]:

- Data Reliability
- Data Security
- Easy Data Access
- Standards
- Cost-effectiveness
- IP Addressability
- No Battery Changes
- Plant-Wide Network

As shown in **Figure 4**, as the channel load increases to full capacity in a LoRaWAN-based system, the collision rate increases significantly to the point where 20% to 30% of messages can be lost in a network that transmitting a few hundred messages a minute [6]. While this may be enough for systems transmitting a relatively small amount of messages in large gaps of time, it may not suffice for the 'data reliability' factor craved by IWSN users.

Furthermore, the completely asynchronous nature of LoRaWAN makes it so that anytime a gateway is transmitting information down to nodes, it is not listening and is therefore losing traffic. The synchronous and slotted Symphony Link protocol allows for a level of QoS assurance by suppressing unimportant traffic and allowing more critical traffic through to the gateway. The network is safeguarded through Public key infrastructure (PKI), real-time advanced encryption standard (AES), and transport level security (TLS). Since the architecture is stand-alone proprietary system there is inherently simpler data access. Besides, the lower latency (100ms to 120s) and higher data rate (1 kbps) allows for quicker data throughput and transmission times also easing data access.

Industrial Design Examples

Oil and Gas

A recent survey by Accenture revealed that 80% of oil and gas (O&G) companies expect to continue to invest in digital technologies over the next 3 to 5 years despite the current low oil price environment [10]. Flow rate and pipe pressure sensors can be installed on O&G equipment such as oil pipelines reducing the risk of leaks and ruptures to avoid some potentially catastrophic environmental consequences. With nearly 2.5 million miles of pipeline in the U.S., the combination of long range and data reliability that LoRa offers can provide a solution.

Asset Monitoring

Plant-wide networking where it may be necessary to track tens of thousands of assets with parameters such as location, temperature, humidity, and vibration requires a long link range, data reliability, and a high network capacity. While the most common IWSN WirelessHART can connect up to 30,000 devices within a 200 meter range, LoRa with the Symphony Link MAC can control up to 250,000 endpoints up to 11 kilometers [13]. There is a myriad of potential LPWAN applications for IIoT, all require a level of customization for parameters such as placement of the nodes, transceiver selection, sensor/actuator type, energy storage and power management,

Average Antenna Gain		
Directionality	**Antenna**	**Gain (dBi)**
Directional	Panel	9-20
	Yagi	~11
	Horn	10-20
Omni-Directional	Parabolic Dish	20-40
	Rubber Duck	3-5
	Whip	0-2
	Paddle	~3
	Mobile/In-Vehicle	0-5
	PCB	2-5
	Chip	0-3
	GPS Patch	0-3
	Dome	2-7

Table 3: Average Antenna Gain [11]

and finally antenna type. The choice of antenna depends upon the requirements such as harsh environmental exposure, space requirements, budget, necessary range, and polarization.

Choice of Antenna

Quick Basics Brush Up

Three key parameters in understanding the antennas that are used in LoRa and other LPWANs are as follows: directivity, gain, and VSWR. Directivity is a measure of the concentration of a beam from the radiating element. For instance, a horn antenna has a very high directivity as compared to an Omni-directional patch antenna. Gain is a measure of the total power radiated from the antenna. An engineer assessing any antenna would have a pretty good idea of what their looking at just by analyzing the gain along with the antenna polar diagram – the graphic representation of the radiation pattern. VSWR, or voltage standing wave ratio, describes the power reflected back from an antenna. Theoretically, a perfectly matched (50 ohm) antenna would have a VSWR of 1:1 and reflect no power with all the inputted energy radiated into free space. **Table 1** overviews the average gain of some commonly used commercial off-the-shelf (COTS) antennas.

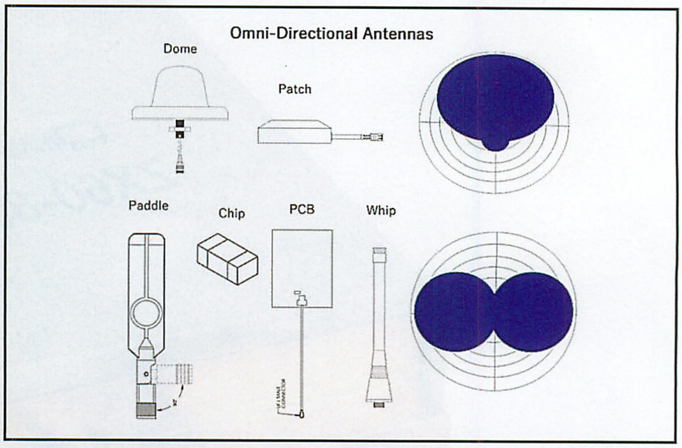

Figure 5 • Omni-directional antennas that are often used in LoRa modules with basic 2D illustration of radiation pattern [11].

LoRa Antennas

For LoRa networks, the range of the system does not depend as heavily on the gain of the antenna as it does the sensitivity of the receiver. Still, the combination of receiver sensitivity, transmit power, and antenna gain in low operating frequencies all contribute to the link budget as shown in Friis transmission equation listed below:

$$P_R = \frac{P_T G_T G_R c^2}{(4\pi R f)^2}$$

Where P_R is the power received by the antenna, P_T is the power transmitted power, G_T is the gain of the transmitting antenna, G_R is the gain of the receiving antenna, c is the speed of the light, R is the range between the antennas, and f is the operating frequency. For instance, the Semtech SX1272 transceiver uses MMIC HPAs to offer +20 dBm of power output and the LoRa modulation technique can bring the receiver sensitivity to -137 dBm. Furthermore, the sub-GHz transmit frequencies inherently have longer wavelengths to maximize range as well. Both LoRa end-devices and gateways typically employ

Length of Wire Antenna for LoRa Module			
LoRa Frequency Band (MHz)	**Region**	**Length (Inches)**	**Length (cm)**
433	Asia	6.5	16.5
868	Europe	3.25	8.2
915	United States	3	7.8

Table 4 • Length of Wire Antenna Per LoRa Frequency Band.

Omni-directional rubber duck antennas with gains as high at 5 dBi. Omni-directional onboard antenna variants such as PCB or chip antennas can also be leveraged so as to save space on the module; experimentation from hobbyists have yielded ranges up to 9 km [12].

Typically, rubber duck antennas are generally the most expensive, have the highest gain, and exhibit the most uniform radiation in all directions. PCB antennas typically have a lower gain but can be implemented in a package, still, they can be quite large at low frequencies. Chip antennas normally exhibit the least gain and, while they are technically Omni-directional, may have a level of directionality where the chip needs to be pointed in a certain direction in order to maximize range. The cheapest solution is the wire antenna where many hobbyists simply cut wire based on the operating wavelength and solder it onto the U.FL connector head, naturally, this is not a long-term solution although it may suffice for the prototyping stage. Table 3 lists the length of the cut needed per frequency band.

The rubber duck (whip), chip, PCB, and wire antennas are all linearly polarized and will need to be installed so that the polarization is in the same direction in order to function. LoRa modules that employ GPS tracking need omnidirectional circularly polarized antennas such as coil (helical) and patch antennas where there is maximum radiation pattern in a certain direction. Ultimately, the high sensitivity of the receiver affects the link budget where the gain of the antenna is of lesser consequence. Moreover, most antennas can handle the maximum rated +20 dBm of continuous power from LoRa transceivers so the main limiting factors are the environmental conditions, space, and budget. Outdoor applications will often need IP67 or above rated antenna/connectors (if using an external antenna) in order to ensure long-term functionality of the node. Whereas, space constrained node placements may need to leverage an onboard antenna such as a PCB or chip antenna.

Conclusion

LPWANs serve a unique niche of wireless connectivity that high throughput, WiFi and cellular applications cannot quite match. Not every application needs to stream 4K videos and, in the instances where small amounts of data in the form of updates are needed, LPWANs are the answer. While the LTE-M1 LPWAN will now be deployed where current Verizon 4G networks are (practically everywhere in the U.S.), it is a licensed network and therefore has higher associated costs; this is also not necessary for stand-alone IWSNs. The unlicensed LoRa network has a budding open source community where innovation is constantly occurring (and where base stations are being put online), allowing for this option to not only be ideal of consumer applications but also giving it tremendous potential in industrial applications. The fact that the LoRa modulation technique is not UNB actually allows for a fair amount of throughput (~ 1 kbps) as compared to other LPWANs, making it a more practical option for IIoT applications. The plethora of LoRa chipsets allow for a level of customization for endpoints that is well-documented in the open source community, still, the choice of antenna may not be as highlighted and can therefore be a pain point in LoRa deployments.

About the Author

Mark Miller serves as a Product Manager for L-com Global Connectivity.

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MIMO and Beam-Steering Modeling in NI AWR Design Environment Supports 5G

By Dr. Gent Paparisto and Dr. John Dunn

Physical technologies required for 5G realization are increased spectrum and new circuitry, as well as efficient power schemes for amplifiers.

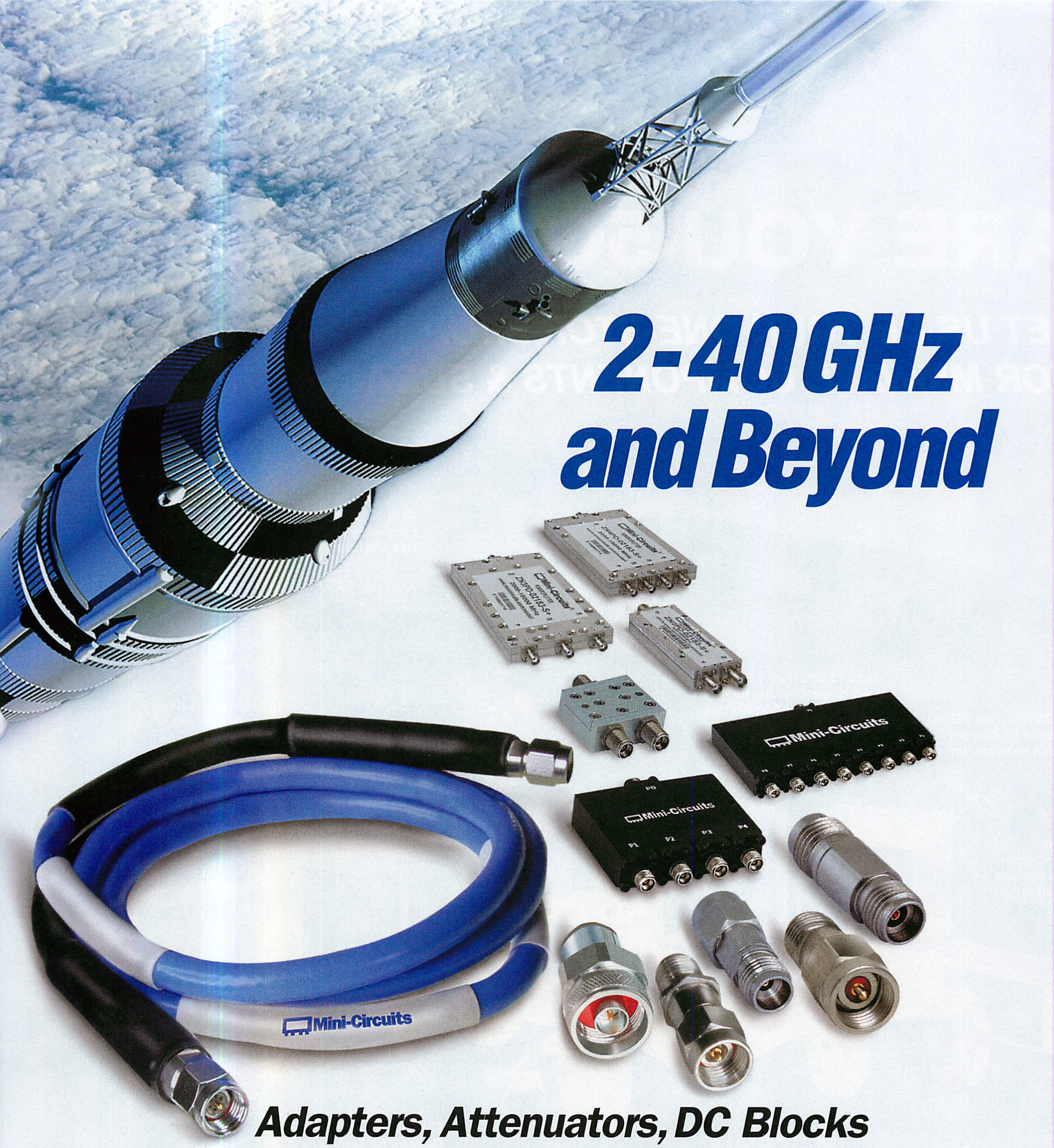
Introduction

5G represents the next milestone in mobile communications, targeting more traffic, increased capacity, reduced latency, and energy consumption through various technologies such as massive multiple-in-multiple-out (MIMO) and beam-forming antenna arrays, mmWave spectrum use, and carrier aggregation. Initial deployment is expected to begin in 2020, and, according to Nokia, there will be some 5G communications implemented in the 2018 winter Olympics.

Physical technologies required for 5G realization are increased spectrum and new circuitry (amplifiers, passives, and antennas), as well as efficient power schemes for amplifiers in mobile and base stations and smaller cells in distributed systems.

(Continued on page 34)

Figure 1 • High data rates, increased capacity, and low power specifications in 5G will require that communication system antennas be designed for maximum efficiency.


2-40 GHz
and Beyond
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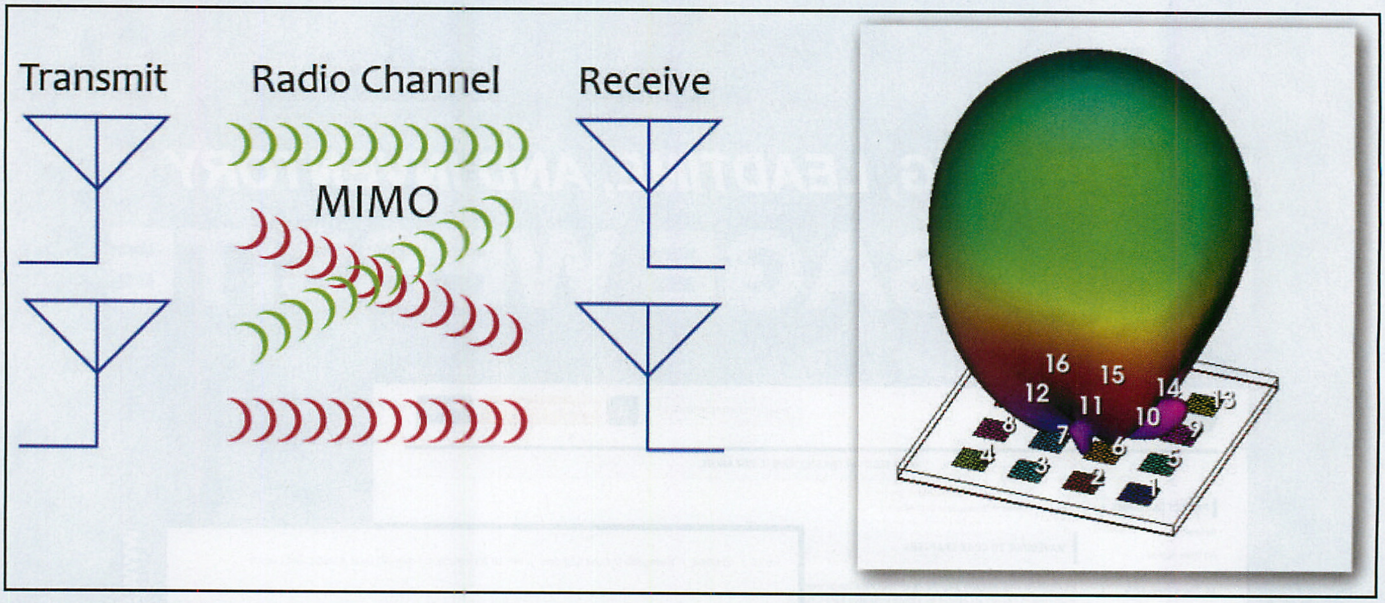


Figure 2 • MIMO and beam-forming array antenna configurations for 5G.

Improved antenna systems are a critical enabling component of the proposed new 5G communications standards currently under development. As shown in Figure 1, high data rates, increased capacity, and low power specifications for 5G will require that communication system antennas be designed for maximum efficiency and throughput with narrow, directed beams. As a result, RF system engineers need to include the antenna characteristics in their simulations to correctly design the entire transmit/receive system.

New antennas geometries such as MIMO/Massive MIMO and integrated phased arrays will be required for 5G. As Figure 2 shows, it is important to remember that MIMO does not go from a single transmit antenna to a single receive antenna, but rather the output goes to multiple receivers, making 5G antenna design very complex.

MIMO and Beam Steering Model Technology

The potential of Massive MIMO will bring over 10x in capacity improvement and over 100x reduction in power consumption. Figure 3 shows how MIMO antenna arrays enable more efficient transmission of power with higher capacity.

As a result of the complexities of 5G antenna design, RF system engineers will need to include the antenna characteristics in their simulations to correctly design the entire transmit/receive system. NI AWR Design Environment, inclusive of Microwave Office circuit design software, Visual System Simulator™ (VSS) system design software, and AXIEM planar and Analyst™ 3D finite element method (FEM) electromagnetic (EM) simulators, helps engineers develop the technologies that will make these advances possible.

This application note presents several practical examples commonly encountered by the RF systems engineer and showcases advances in MIMO and beam-steering model technology within Visual System Simulator™ (VSS) system design software. Detailed examples of the models being utilized in real-world systems are shown, including:

- Individual antenna patterns for array models
- Coupling of nearby elements
- Modeling of different array geometries, including imperfections and defects of elements

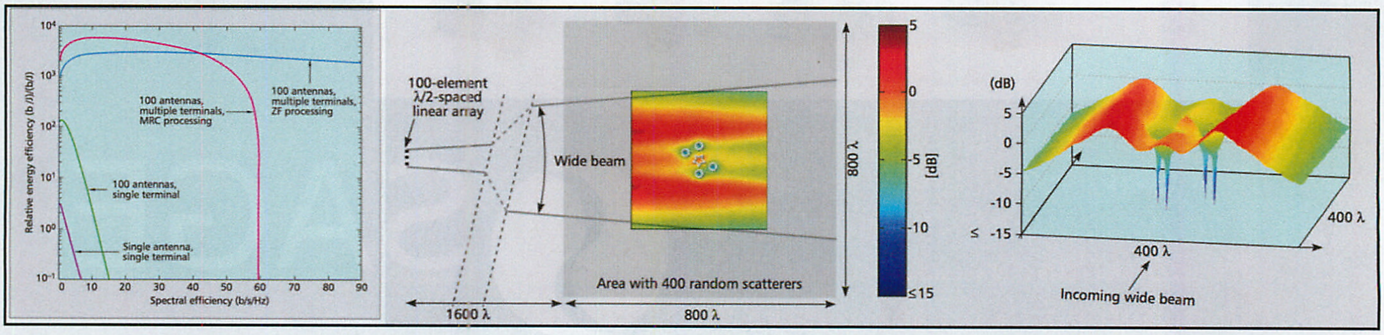


Figure 3 • MIMO antenna arrays enable more efficient transmission of power with higher capacity. (Source: *IEEE Communications* Magazine, Feb. 2014)

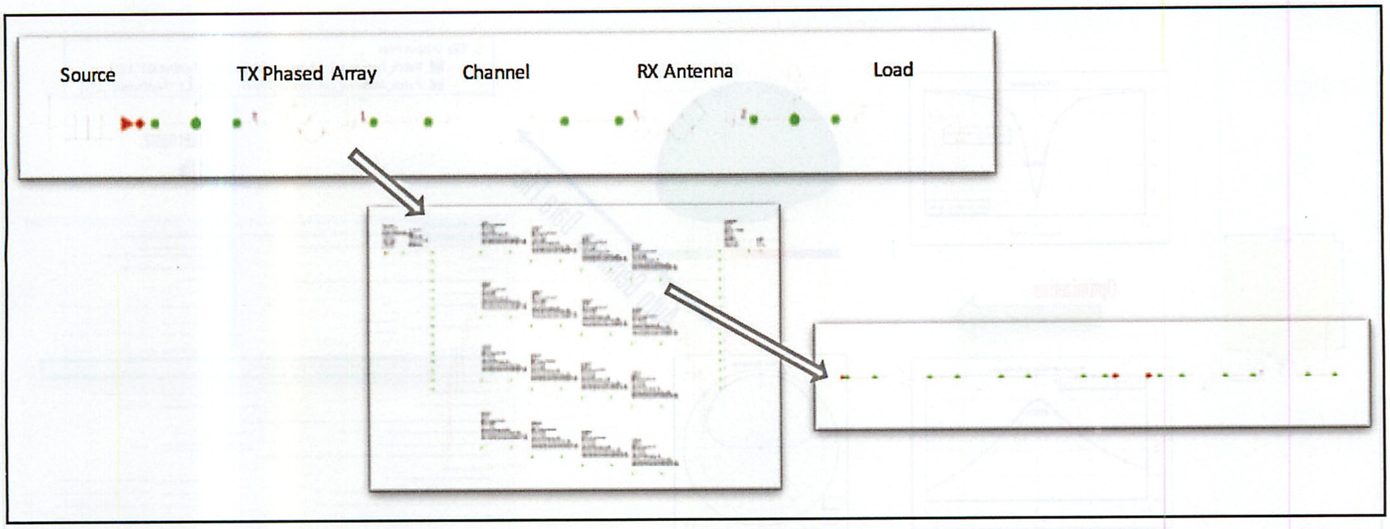


Figure 4 • System-level phased-array design of the RF link.

- Active impedances observed at each element of the array
- Different RF links for each element.

Phased-Array System Design in VSS

In VSS the recently enhanced beam-steering behavioral model provides accurate characterization for a distributed feed architecture. User can define the desired splitter/combiner architecture, along with the desired beam angle and observation angle. The model automatically calculates the phase and the input power required for each element and gives the user the array performance. The phased arrays may be investigated in transmit or receive mode, or combined to model a complete transmit and receive chain and evaluate the end-to-end system performance.

The MIMO model provides the flexibility to further define the RF link connected to each antenna element, including the filtering and amplification for each element. A common application would be studying requirements for amplifier performance in an array where the center elements are being excited at higher power. Furthermore, such setup would allow users to investigate array operation when elements are excited with non-correlated signals, resulting in higher cross-talk and more demanding designs.

Classically, designers would use an electromagnetic (EM) simulator and antenna software for the phased array itself. As a system engineer designing the RF link, it is important to include the effects of the antenna and the phased array into the system-level design. Figure 4 shows a simplified link in VSS.

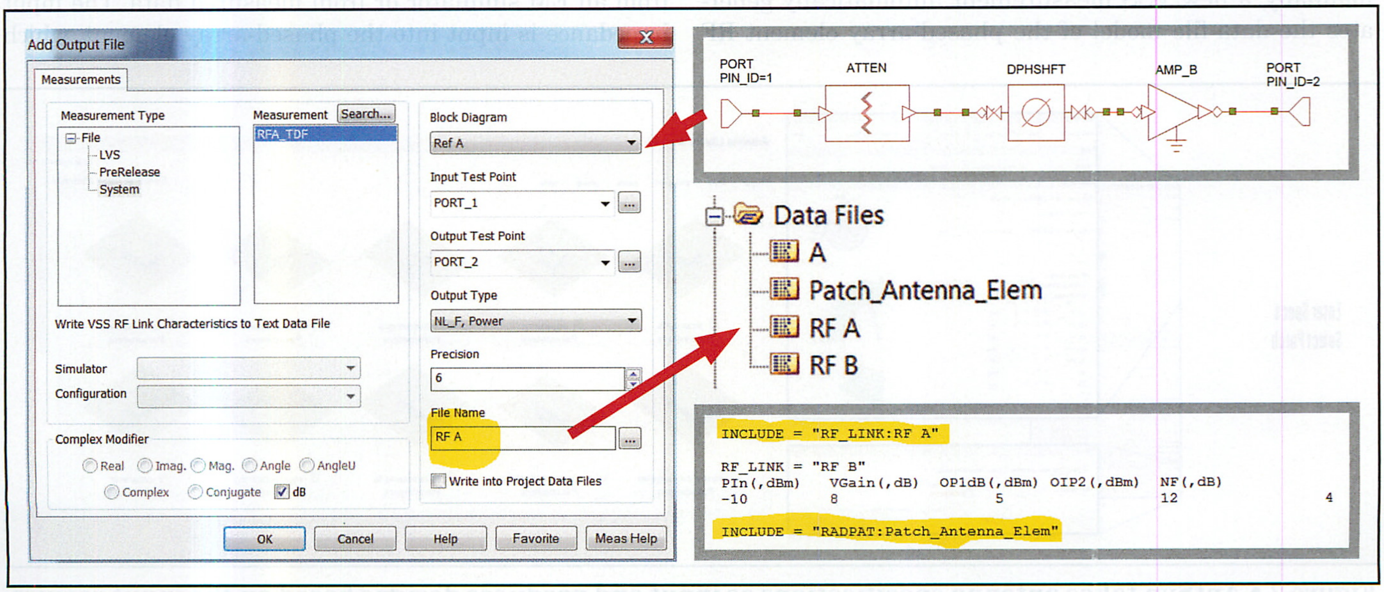


Figure 5 • VSS phased-array element with RF link characterization.

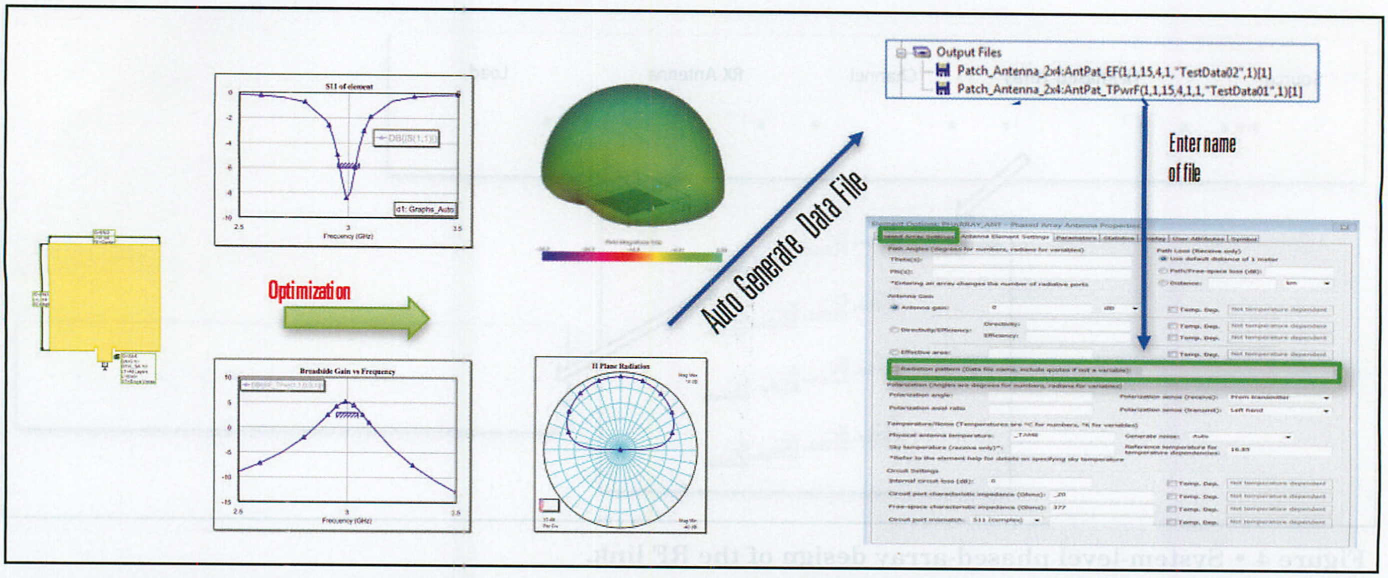


Figure 6 • The element is designed and the radiation pattern is EM simulated in AXIEM or Analyst, which then automatically generates the data file for input into the element.

The second element, the TX phased array, is the system model element in the system simulator that is modeling the phased array.

RF Link Characterization

In VSS the flow for modeling a phased array has been greatly automated. Users can put real antenna patterns into the element, and can actually couple the elements to get coupling effects for issues like nearest neighbors. In addition, the RF links can be individually modeled for each array element.

Figure 5 shows the RF link characterization capability in the software. Rather than having to write text files manually, a new VSS measurement automatically generates the data-file model of the phased-array element RF link. The user starts with the RF link design (top-right) and uses a link characterization measurement to extract the RF link characteristics and save them to a file. The results are then used in the phased-array model.

Element Phased-Array Pattern Measurement

The phased-array element in the Microwave Office circuit simulator can use real antenna patterns, derived from an EM simulator, as shown in the simple patch antenna example in Figure 6. The user designs the element and measures the radiation pattern in either AXIEM or Analyst EM simulator. The antenna patterns in the phased-array element within the simulator come either from an EM simulator or from measured data. The input impedance is input into the phased-array element, which

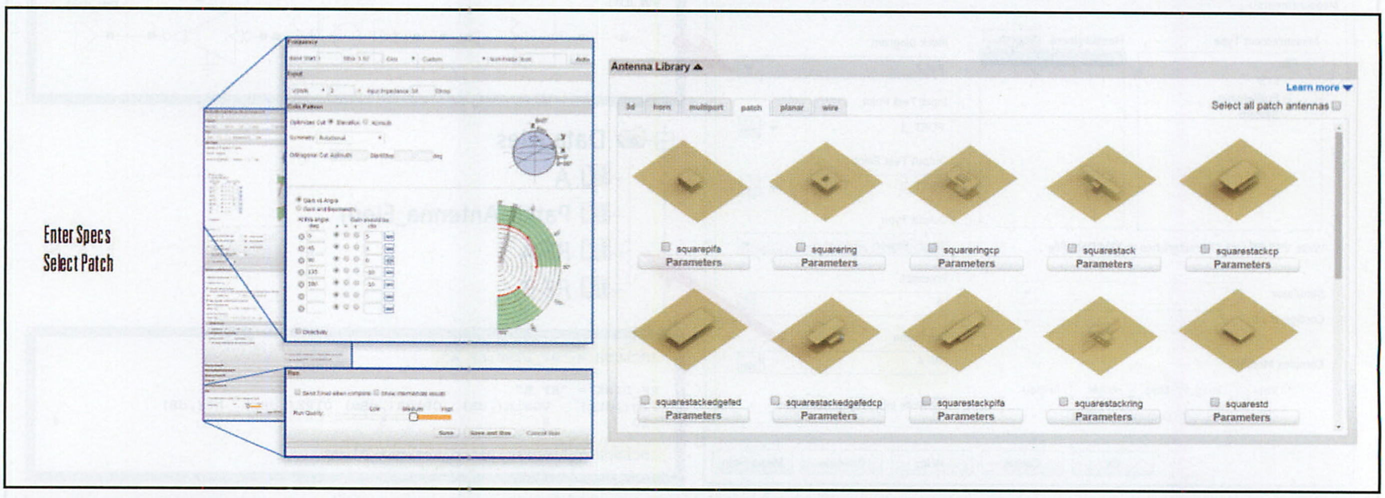


Figure 7 • AntSyn takes antenna specifications as input and produces designs based on the input requirements.

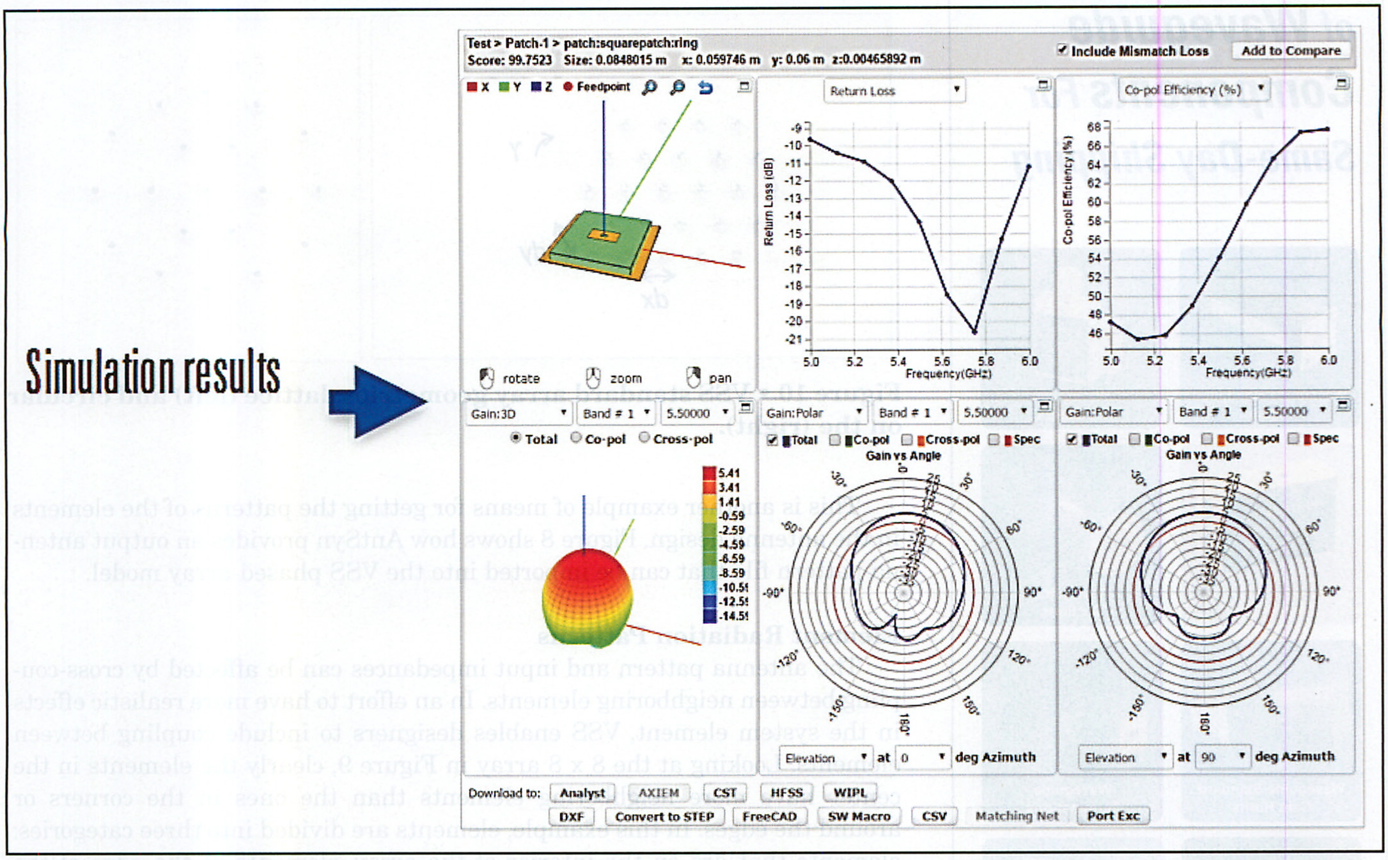


Figure 8 • An AntSyn antenna pattern file can be imported into the VSS phased-array model.

produces the pattern. Then the software automatically generates the data file for the pattern, which is then put into the element.

Phased-Array Element Design

If antenna elements have not been designed yet, users can take advantage of AntSyn™, which offers automated antenna design, synthesis, and optimization. With this tool designers can define their specifications and the software will provide the best antenna designs based on those requirements. It will often suggest antennas that the designer might not have considered, but that the software has determined might be better for the particular application (Figure 7).

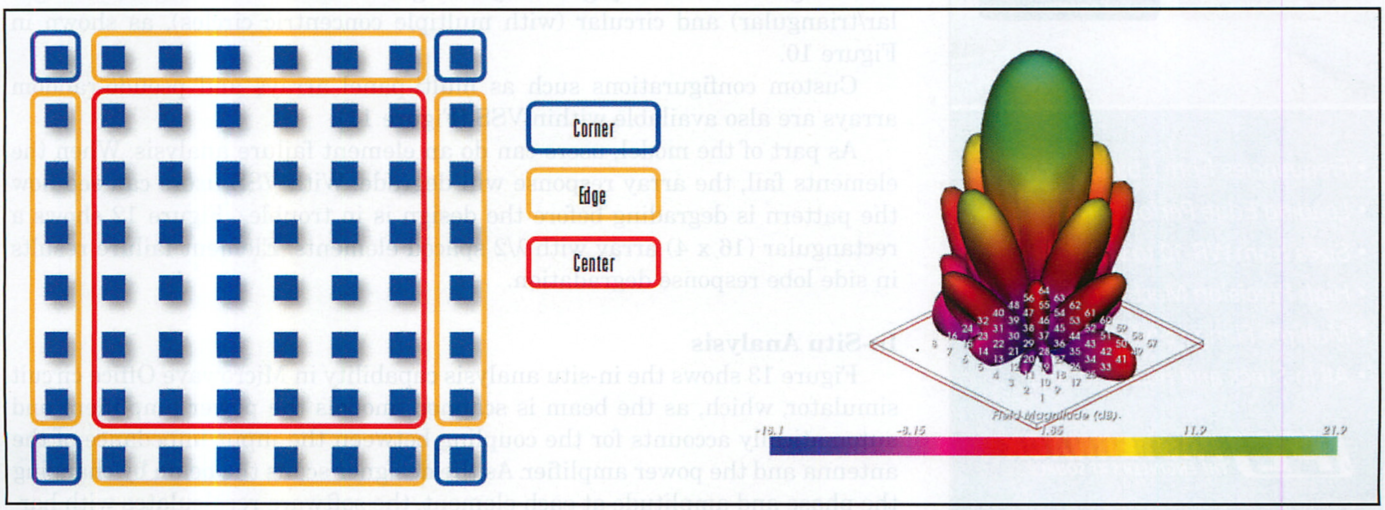


Figure 9 • The coupling elements for center, edges, and corners of the array (left) and resulting EM simulation (right).

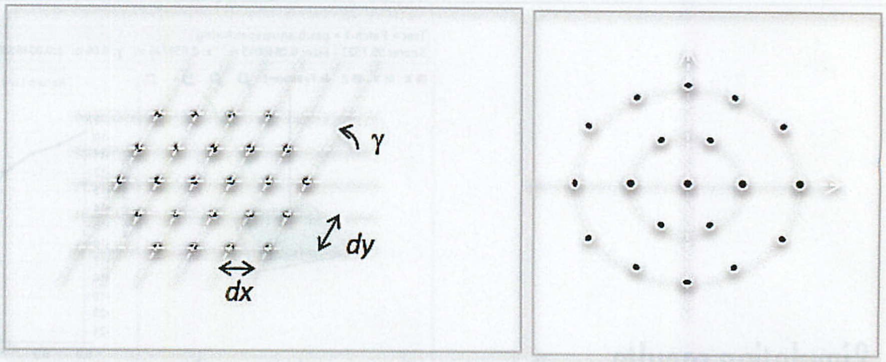


Figure 10 • VSS standard array geometries: lattice (left) and circular on the (right).

This is another example of means for getting the patterns of the elements in the antenna design. Figure 8 shows how AntSyn provides an output antenna pattern file that can be imported into the VSS phased-array model.

Element Radiation Patterns

The antenna pattern and input impedances can be affected by cross-coupling between neighboring elements. In an effort to have more realistic effects in the system element, VSS enables designers to include coupling between elements. Looking at the 8 x 8 array in Figure 9, clearly the elements in the center have more neighboring elements than the ones in the corners or around the edges. In this example, elements are divided into three categories: elements that are on the interior of the array, elements at the edge of the array, and four elements at the corners. These categories can be used to model the specific mutual coupling that is observed by each type of element, resulting in better evaluation of the array response.

In the phased-array element in the system simulator, users can define which pattern and/or which active impedance should be used. The VSS phased-array model can use different patterns for each element, which can be calculated using EM simulations, and mutual coupling effects coming from neighboring elements.

The VSS system model supports a number of different architectures, including standard array geometry configurations such as lattice (rectangular/triangular) and circular (with multiple concentric circles), as shown in Figure 10.

Custom configurations such as multi-panel arrays and pseudo-random arrays are also available within VSS (Figure 11).

As part of the model, users can do an element failure analysis. When the elements fail, the array response will degrade. With VSS users can see how the pattern is degrading before the design is in trouble. Figure 12 shows a rectangular (16 x 4) array with $\lambda/2$ spaced elements. Element failure results in side lobe response degradation.

In-Situ Analysis

Figure 13 shows the in-situ analysis capability in Microwave Office circuit simulator, which, as the beam is scanned, models the power amplifiers and automatically accounts for the coupling between the input impedance of the antenna and the power amplifier. As the designer scans the beam by changing the phase and amplitude at each element, the software recalculates with harmonic balance the power amplifier performance. The AXIEM 3D planar simulator within Microwave Office circuit design software also offers phased-array

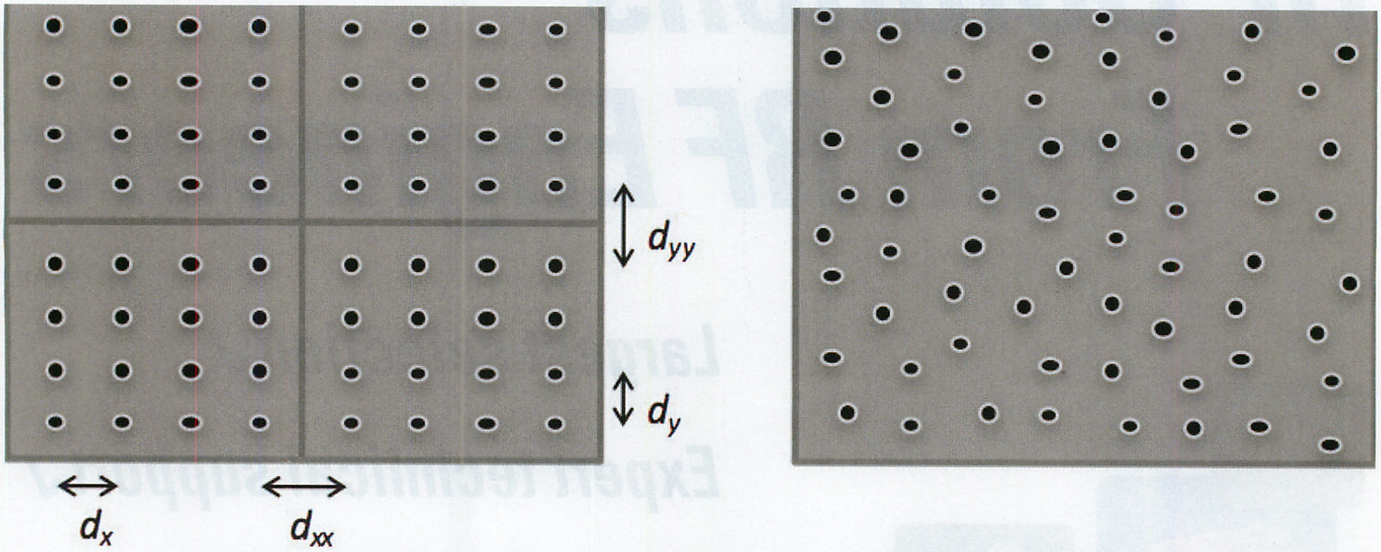


Figure 11 • Custom array configurations: multi-panel (left) and pseudo-random (right).

simulation capabilities. As can be seen in Figure 13, the antenna array pattern is being EM simulated by AXIEM.

What makes these antenna patterns so difficult is that because the elements are being driven by power amplifiers in saturation, as the beam is scanned, the load impedance to the power amplifier changes and therefore the input impedance to the elements changes. A classic example of this is where designers taper the power coming into the antenna so the most power goes to the center elements with less power to the outside elements, which lowers the

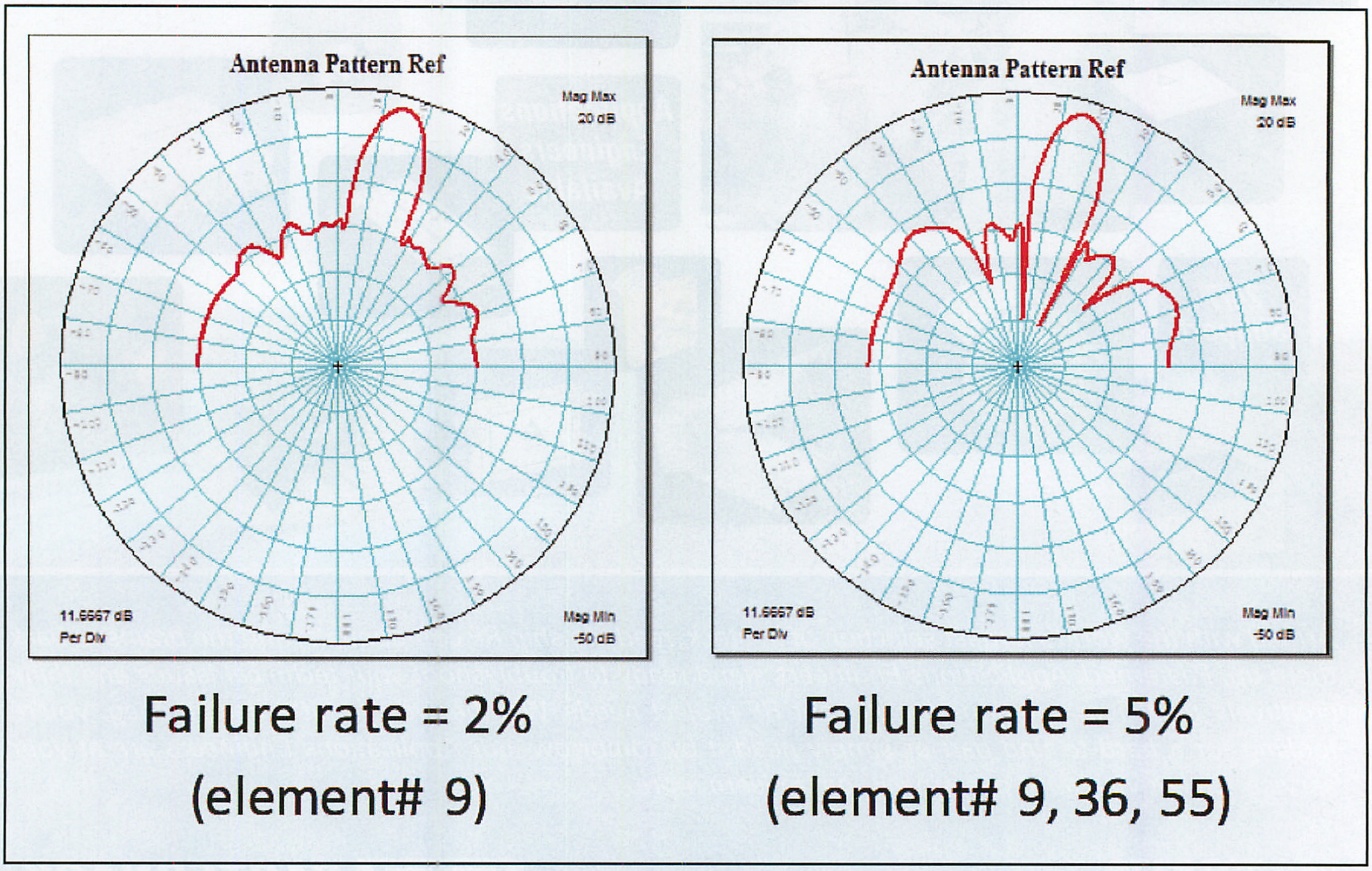


Figure 12 • Element failure results.

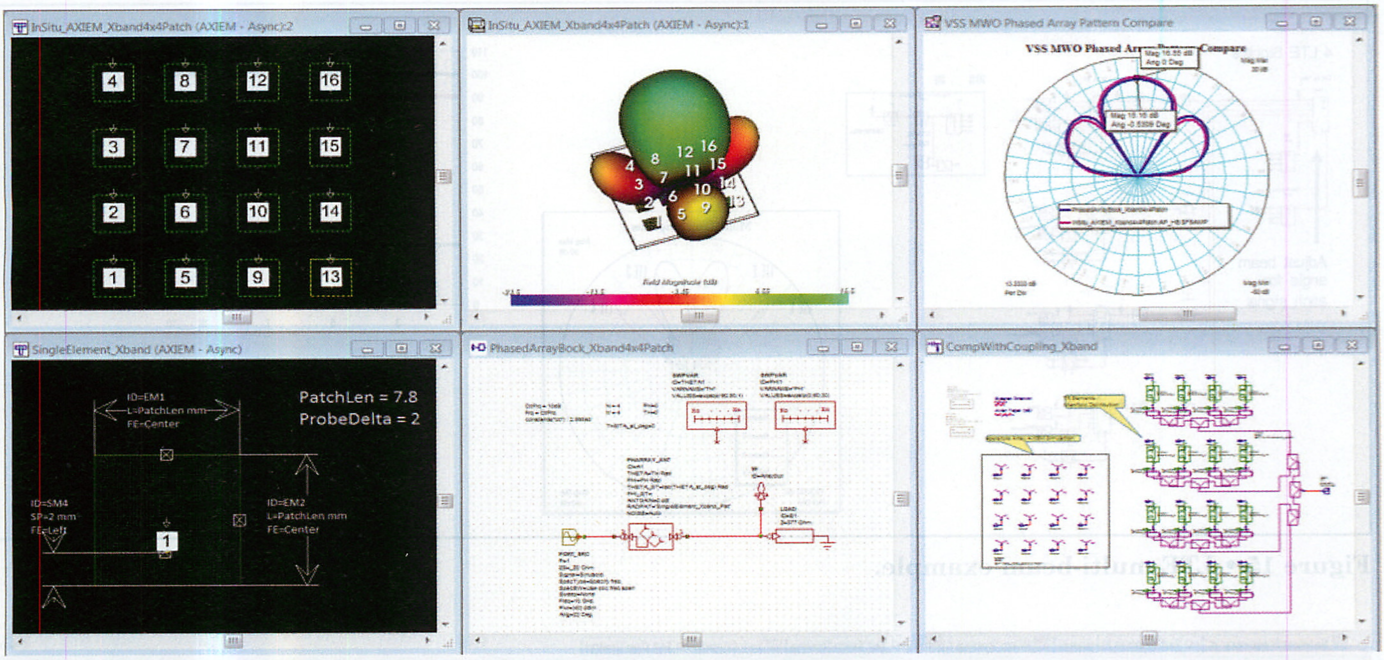


Figure 13 • Antenna array pattern being simulated in Microwave Office circuit design software's embedded AXIEM EM simulator.

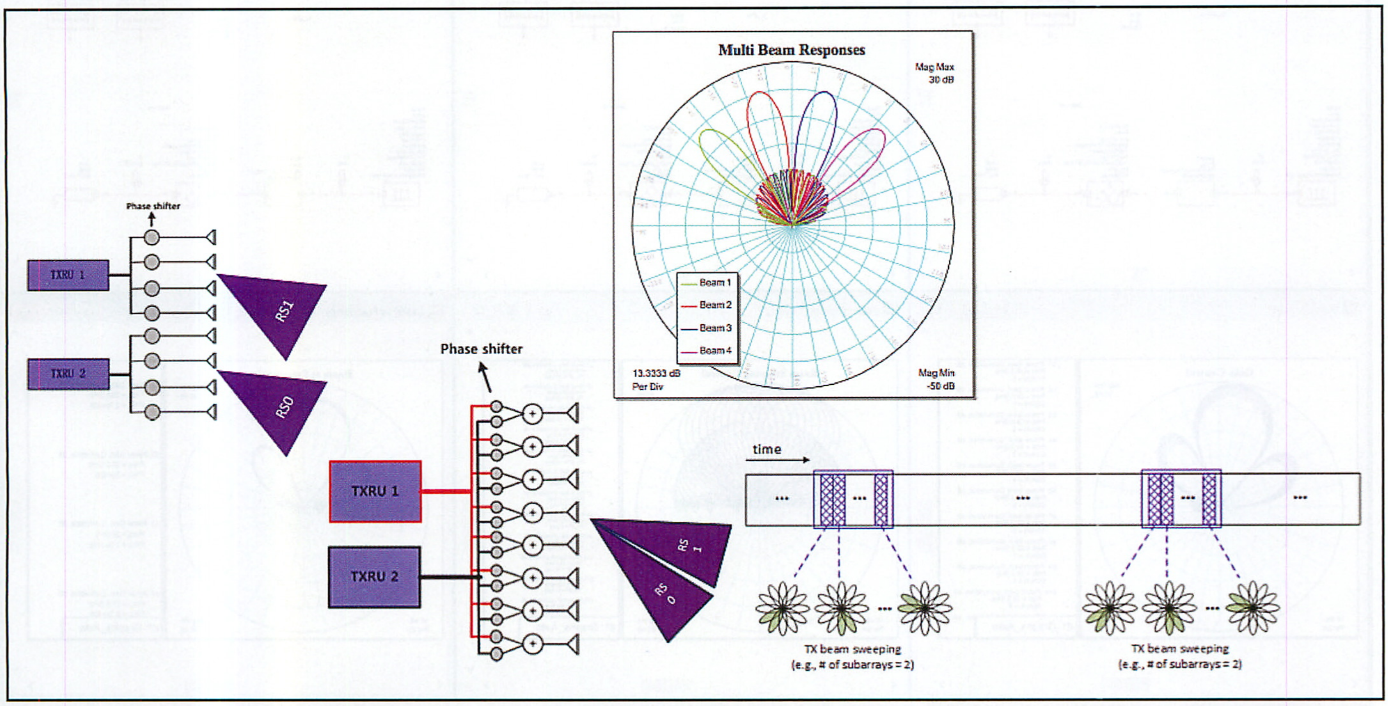


Figure 14 • VSS provides a variety of ways for simulating multiple beams.

side lobes. This drives the power amplifiers of the elements in the middle to saturation much more than the ones on the outer part of the array, possibly resulting in different performance than expected.

Multi-Beam Support

In VSS, designers can simulate multiple beams using the phased-array element, which supports a variety of ways of doing this, including analog, digital, and hybrid beamforming, as well as single beam versus multi-beam

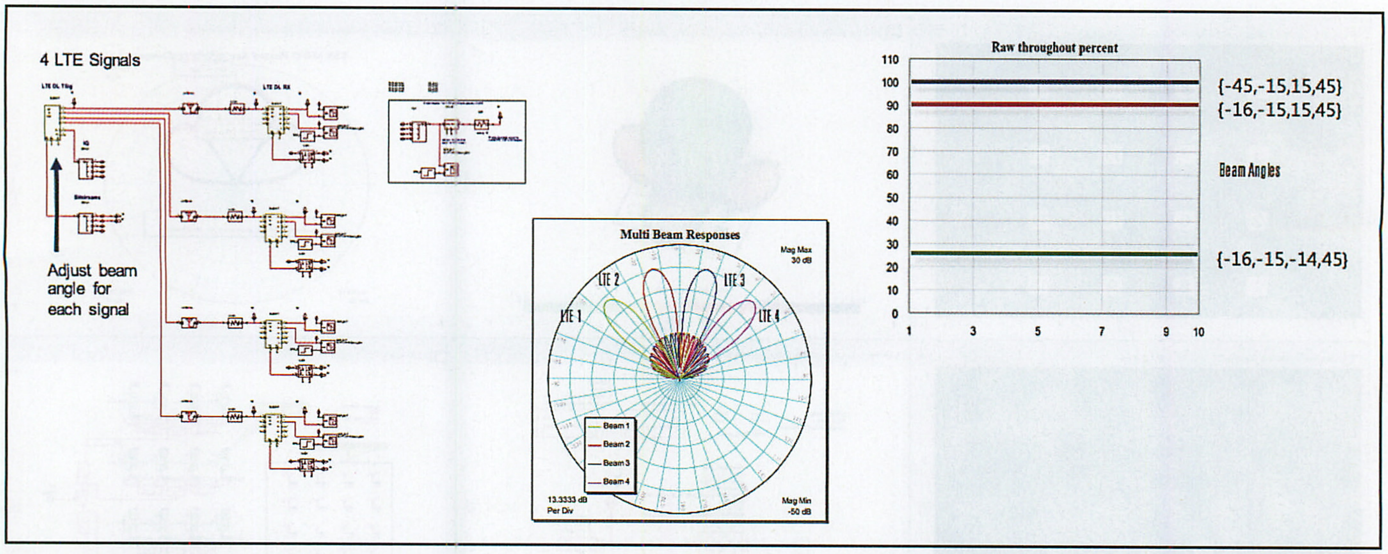


Figure 15 • LTE multi-beam example.

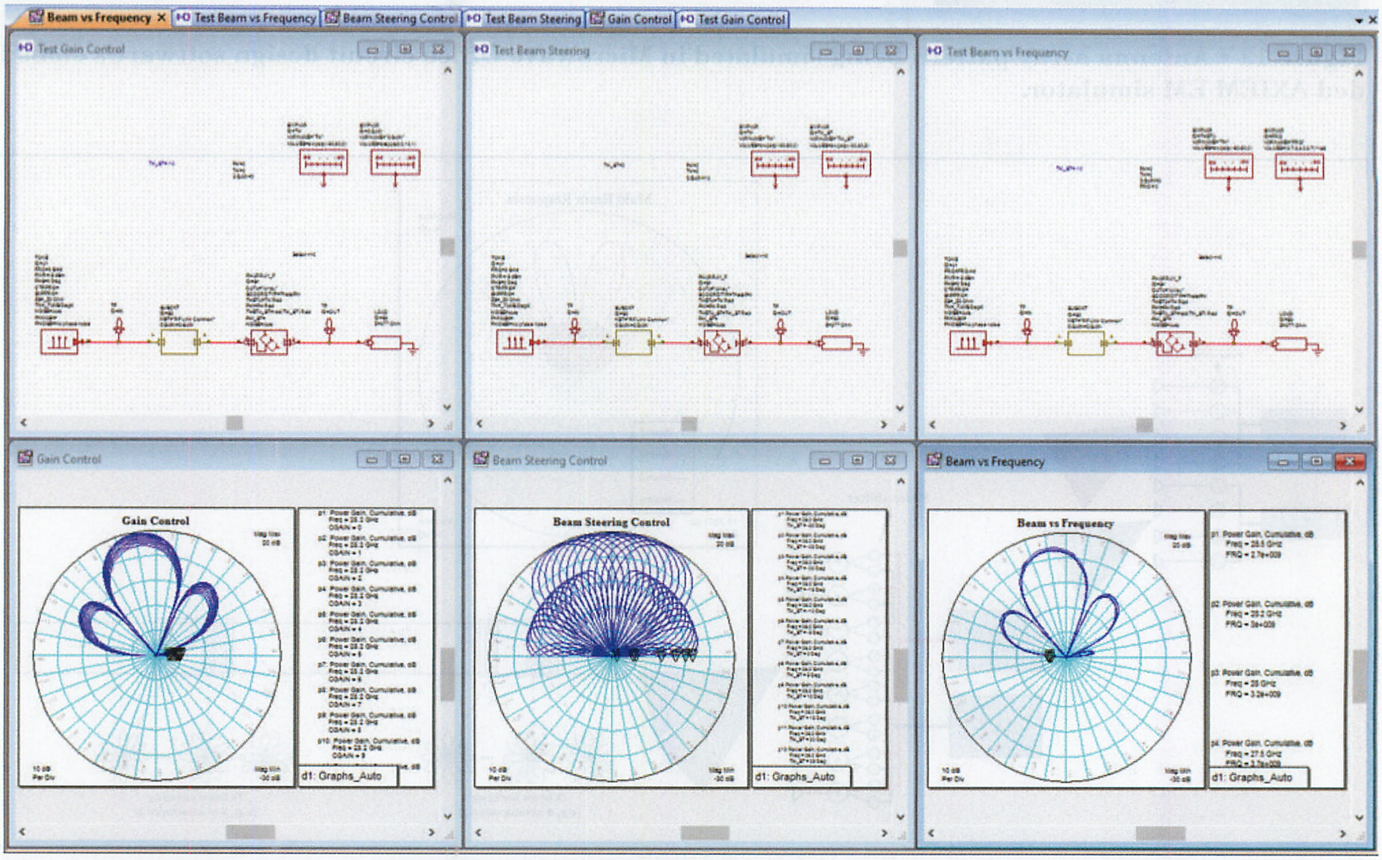


Figure 16 • 28 GHz phased-array transceiver in VSS.

and beam sweeping. Figure 14 shows how VSS enables designers to have multiple beams at different angles coming out of the same array.

In the analog beam-steering method, the RF carrier is sent in and branched out to the elements with an analog phase shifter at the RF frequency of each element. The designer then scans while changing the phase at that center frequency. The advantage of this technique is that it is relatively simple, however, it is not very accurate. A newer method is digital beam forming, where at baseband the designer digitally processes the signal, then upconverts it, getting a much more accurate steer on the beam. The

problem with that is that now each element must have a separate feed, making the feed structure coming into each element much more complex and requiring upconversion at each element. As arrays are getting bigger, hybrid architectures are employed as a mix of digital and RF beamforming.

LTE Multi-Beam Example

Figure 15 is an LTE multi-beam example using VSS. On the left a subcircuit labeled "4 LTE signals" can be seen. That subcircuit contains four LTE signal sources transmitted out of the same phased array, with each signal broadcast at a specific beam angle aimed at four different receivers. As the designer changes the beam angles, the performance of each receiver can be monitored and the system throughput can be displayed, showing the effect of beam steering and beam placement. VSS enables designers to see how accurately they need to control the beams in order to achieve acceptable power and data throughput. They can also monitor a number of other measurements, such as ACPR, EVM, constellation, etc.

28-GHz Phased-Array Transceiver Example

Figure 16 is a VSS mockup of a 4 x 4 phased array prototype developed by IBM and Ericsson. Designers can run multiple tests to evaluate the performance of gain control, beam steering control, as well as array response over a range of frequencies.

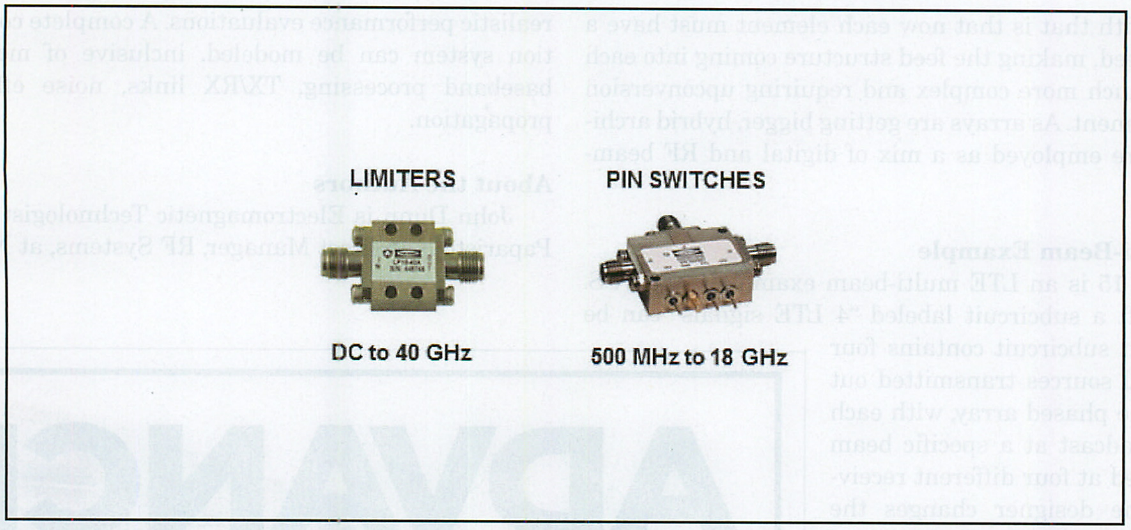
Conclusion

NI AWR Design Environment provides a powerful framework for simulating complex 5G MIMO systems with multi-beam and beamforming capabilities. AXIEM and Analyst EM tools can be used for designing and evaluating the phased-array elements and their interactions. Element radiation patterns are included in phased-array system analysis. The effect of realistic RF links is included in the phased-array assembly to achieve realistic performance evaluations. A complete communication system can be modeled, inclusive of modulations, baseband processing, TX/RX links, noise effects, and propagation.

About the Authors

John Dunn is Electromagnetic Technologist and Gent Paparisto is Product Manager, RF Systems, at NI AWR.

Product Highlights



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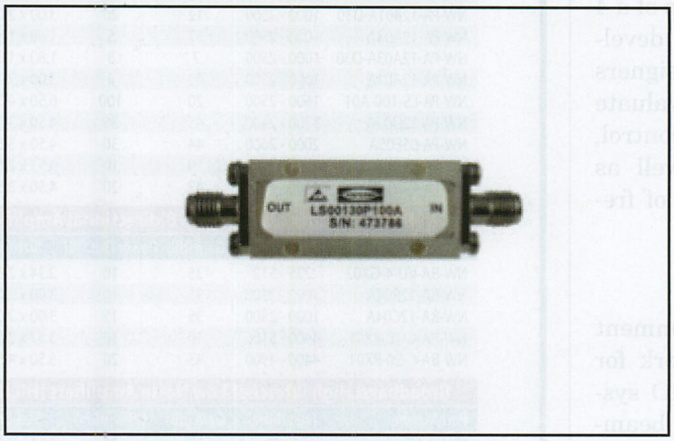

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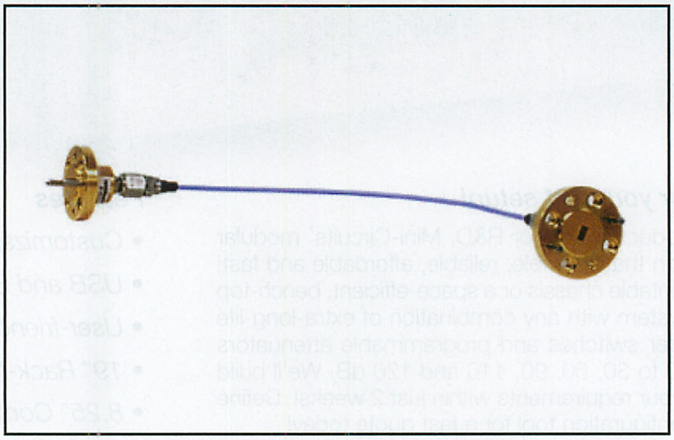

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Model SCW-1212006-S1-F is a 6" long WR-12 waveguide cable. The frequency range of the waveguide cable is 60 to 90 GHz. It allows for varied orientations of waveguide to waveguide connections. The cable has a typical insertion loss of 3.5 dB and a nominal VSWR of 1.5:1. It is flexible with maximum bend radius of 0.20". Other lengths are offered under different model numbers such as SCW-1010006-S1-F and SCW-1515006-S1-F.

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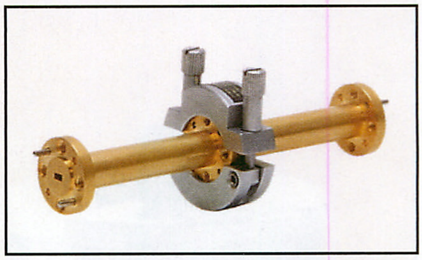

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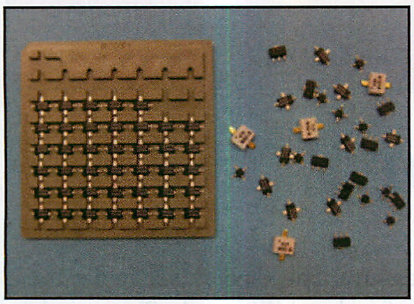

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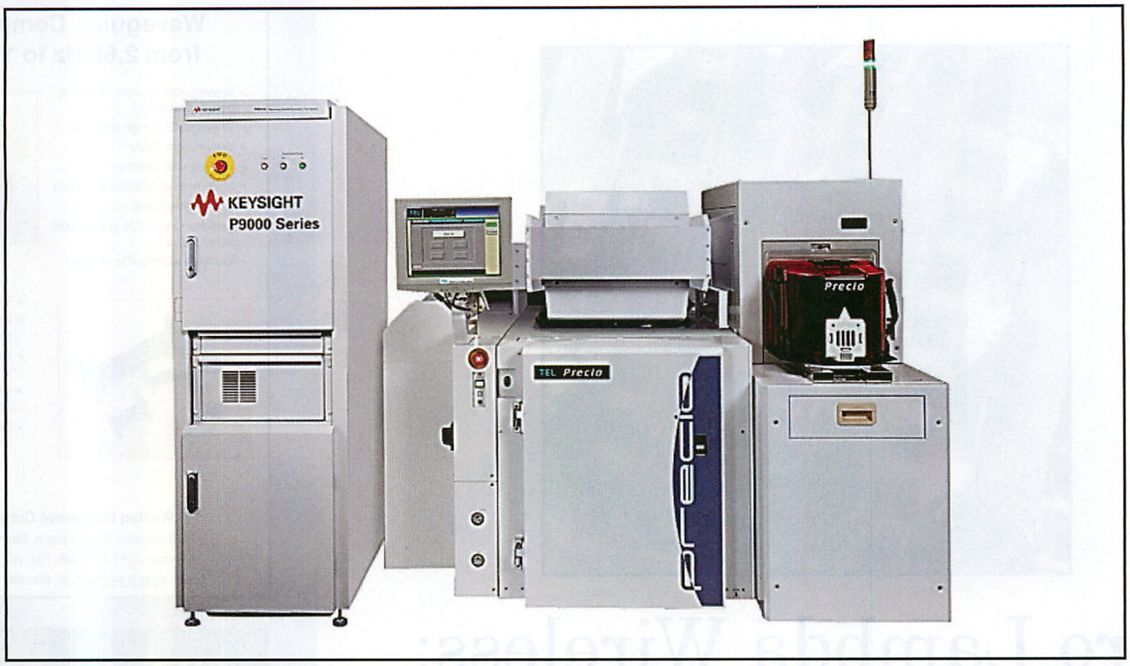

Massively Parallel Parametric Test System Reduces Cost-of-Test

Keysight Technologies announced the third generation of its P9000 series massively parallel parametric test system. The system accelerates the fast ramp of new technology and reduces the cost-of-test in the development and manufacturing of advanced semiconductor logic and memory ICs. For example, with the new types of device structure and higher performance, the required amount of parametric test data per advanced technology node (less than or equal to 20 nm) is drastically increasing.

When the P9000 was introduced, it enabled 100-pin parallel measurements for multiple devices on silicon wafer by using a dedicated per-pin test unit module. The module had all the typical measurement functions required for parametric test (e.g., voltage, current, capacitance, pulse, and frequency). In addition, direct charge measurement (DCM) technology enabled fast, 100-pin parallel capacitance measurements.

The second generation of the P9000 included the Keysight developed rapid Vt measurement technology. The rapid Vt measurement technology provided single measurements of threshold voltage (Vt) that were more than four times faster than any of the conventional test methods. In addition to 100-pin parallel measurement, faster single parameter measurements provided by the DCM and rapid Vt measurement technology enabled further improvements in test speed. Thus, advanced foundry and memory companies have adopted the P9000 platform (first and second generations) as their next-generation parametric test solution.

With the introduction of the third generation of P9000—with the new per-pin parametric test module, the Keysight P9015A—the tester has further shortened the time of capacitance measurements to address the trend of increasing test volumes of capacitance due to multi-layer interconnection and new device structure. The new module enables the measurement of leaky capacitance by using its enhanced DCM technology and enables greater than two times faster single capacitance measurement with good data correlation for various type of capacitance (compared to conventional LCR meter). In addition, the 100-pin parallel capability of capacitance measurement allows customers to achieve further throughput improvement.

"Hundreds of the P9000 are already being used in R&D and in volume production by a number of semiconductor companies, such as advanced logic foundries and memory manufactures," said Masaki Yamamoto, vice president and general manager of Keysight's Wafer Test Solutions. "Keysight continues to enhance the P9000 to further reduce the customer's time-to-market and reduce the cost-of-test. The third-generation P9000 provides the fastest parallel parametric test solution, with a 100-pin, 'TRUE' parametric per-pin module, even with the test structures used in conventional test systems."

Keysight Technologies
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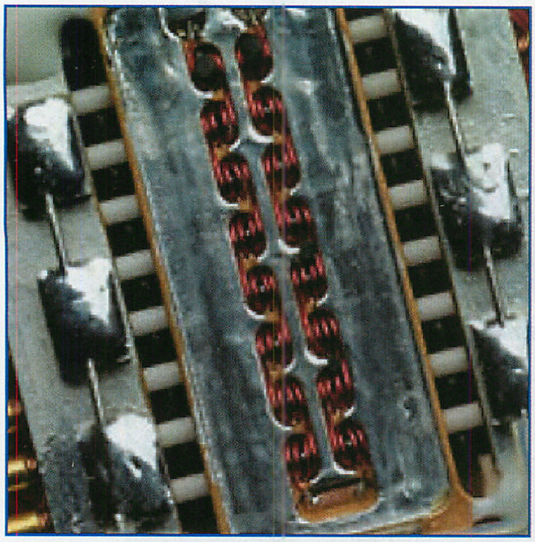

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All of our products utilize a YIG single crystal structure, a ferrimagnetic material that resonates at microwave frequencies from 500 MHz to 50 GHz. The frequency is directly proportional to the applied magnetic field of the YIG material. For oscillators, a single YIG sphere is used as the resonator element in a tank circuit to generate very wide tuning sources with excellent phase noise characteristics. For filters, a number of YIG spheres are used as stages (poles) in both band-pass and band-reject filter configurations.

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We offer not only the deepest standard product line of YIG oscillators, synthesizers, filters, multipliers, and benchtop instruments; we've also thought ahead and designed complementary drivers for nearly every product in our portfolio. So you can employ them right out of the box. Every product is supported by a team of engineers that are always ready to help you with your application engineering and product integration challenges.

Review our products and get in touch. We'd be happy to answer any questions you might have about getting the most out of our standard or custom designed YIG products.

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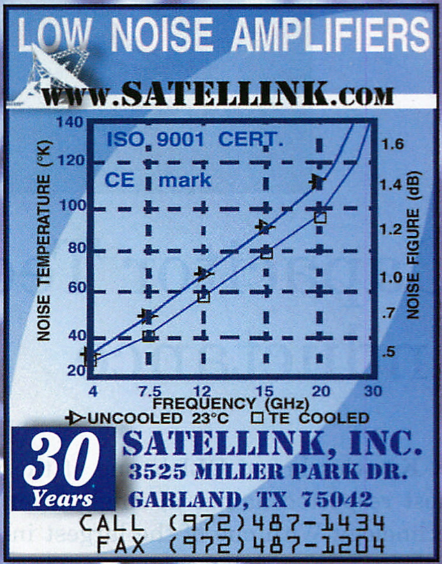
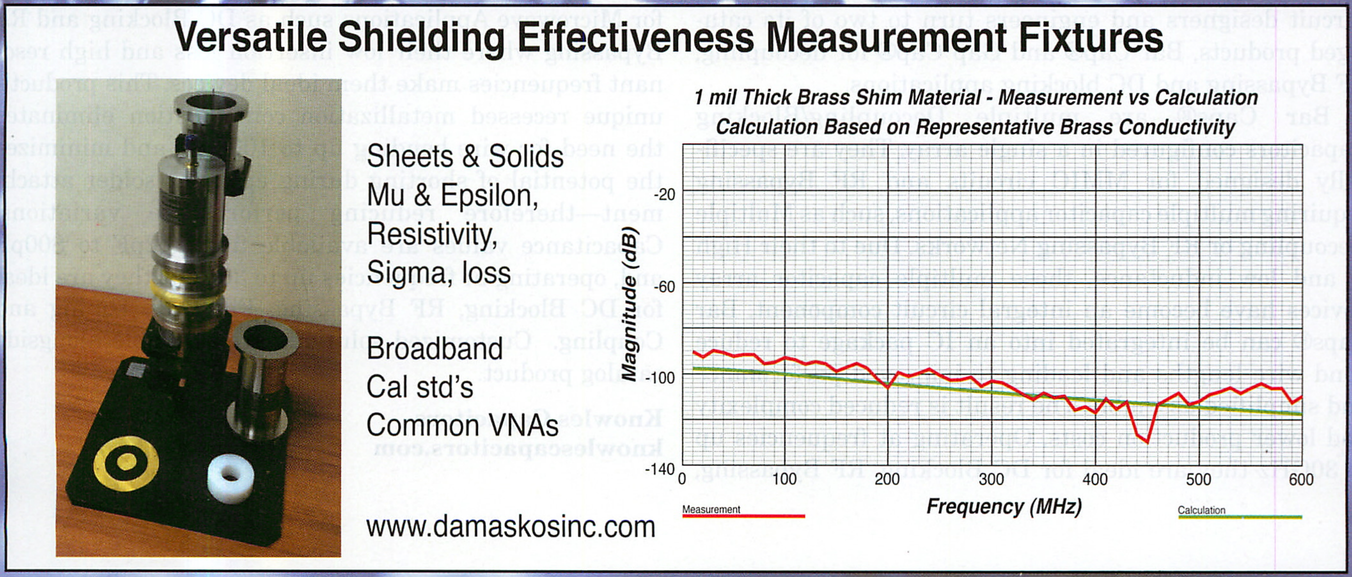
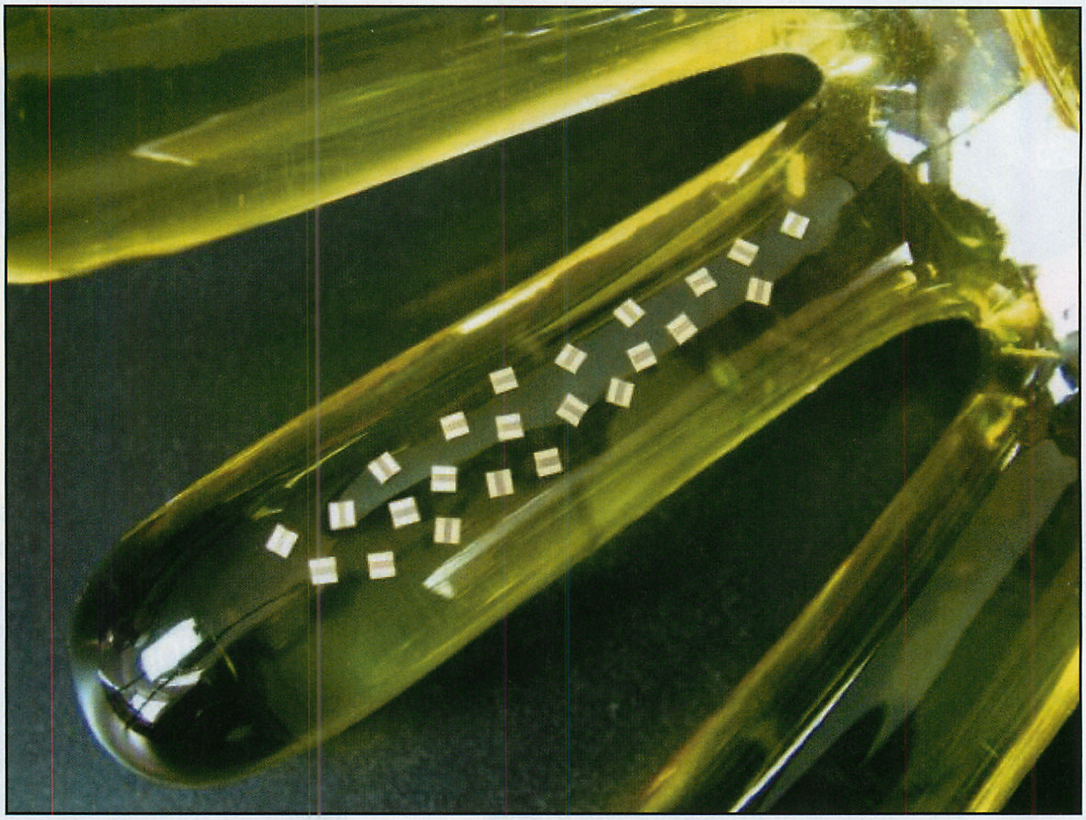
Product Showcase







Capacitor Technology: High Q, Low Inductance

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Gap Caps® are series configured precision Capacitors for Microwave Applications such as DC Blocking and RF Bypassing where their low insertion loss and high resonant frequencies make them ideal devices. This product's unique recessed metallization configuration eliminates the need for wire bonding up to 100GHz and minimizes the potential of shorting during epoxy or solder attachment—therefore reducing performance variations. Capacitance values are available from 0.2pF to 800pF and, operating at frequencies up to 30GHz, they are ideal for DC Blocking, RF Bypassing, Filtering, Tuning and Coupling. Customized solutions are available alongside catalog product.

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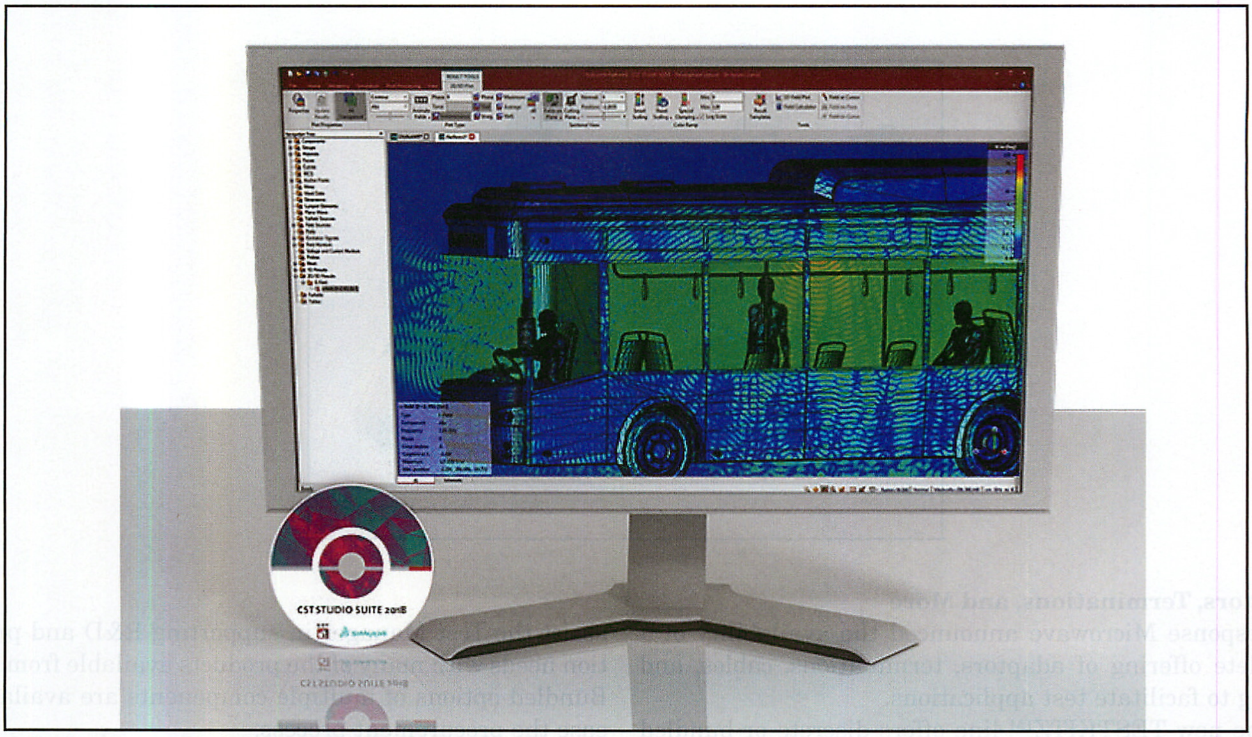

CST Studio Suite 2018 Released

The electromagnetic (EM) simulation software CST STUDIO SUITE is used by industry-leaders to design, analyze and optimize components and systems across the EM spectrum. The CST® Complete Technology approach means that all solvers are available within a single graphical user interface, with strong links between different solvers.

The 2018 release of CST STUDIO SUITE develops on previous success with a range of new features for simulating entire systems with hybrid methods. One key strength of CST STUDIO SUITE is the ability to link multiple simulations with different solvers into a single workflow with System Assembly and Modeling (SAM). In 2018, the improved Assembly Modeler offers users a more efficient way to combine multiple components into a system employing a 3D environment optimized for complex models. This is complemented by new features for EM/circuit co-simulation and the Hybrid Solver Task providing bidirectional solver coupling between the Time Domain and Integral Equation Solvers – a major step forward for hybrid simulation.

For bio-EM simulations, the voxel poser tool, previously a separate product, is now integrated directly into the CST STUDIO SUITE interface, offering users direct access to the voxel poser during the modeling process. Body models using the tetrahedral mesh can now move realistically to simulate breathing, which is important in the design of medical devices. Filter Designer 3D, CST's tool for designing cross-coupled filters and calculating coupling matrices, is now connected directly to the powerful optimizers in CST STUDIO SUITE. This means that the optimizers have access to the coupling matrix calculation, allowing faster and more intelligent filter tuning.

Photonic and terahertz applications are a growing trend, and CST STUDIO SUITE offers a new alternative interface for these areas, with direct access to optical features. It also now allows simulations to be set up using wavelength rather than frequency. CST STUDIO SUITE 2018 introduces the ability to calculate farfields on multilayer substrates, which is useful both for photonic applications and for simulating antennas printed on complex PCBs. Behind the scenes, the core of the software is as ever fine-tuned to optimize performance on the latest hardware, and CST STUDIO SUITE is being introduced to the Dassault Systèmes 3DEXPERIENCE® platform with links to other SIMULIA tools.

"CST has long had industry-leading solver technology, and in this new release we have leveraged synergies between them resulting in new powerful hybrid simulation methods," said Dr Peter Thoma, Managing Director R&D, CST. "With CST STUDIO SUITE 2018, we're integrating CST software with the Dassault Systèmes 3DEXPERIENCE platform, which connects CAD, PLM, collaboration and other leading edge simulation software, in order to provide a complete multidomain and multiphysics solution."

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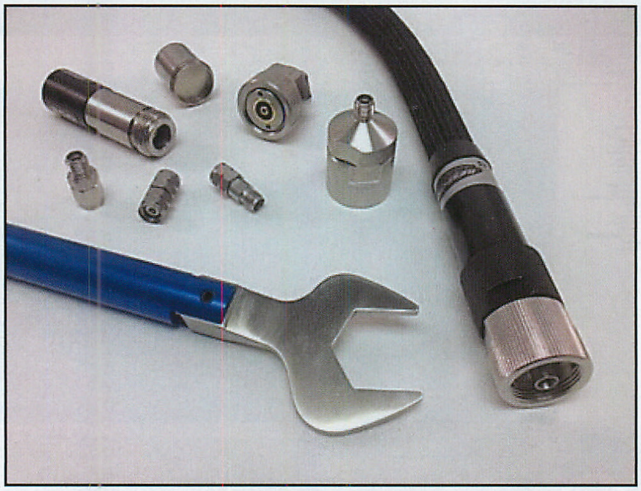
cst.com

Product Highlights



Adaptors, Terminations, and More

Response Microwave announced the availability of a complete offering of adaptors, terminations, cables, and tooling to facilitate test applications.

The new TESTKITZ™ line offers discrete or bundled components operating over the DC-65GHz frequency range. Interface selections within the multi-functional offering are available in SMA27, N18, TNC18, 3.5mm,2.92mm, 2.4mm, 1.85mm and NMD to address the current diversity of today's test equipment. This line will assist the Test Manager in supporting R&D and production needs with many of the products available from stock. Bundled options of multiple components are available to ease the procurement process.

All product is robust passivated stainless steel and interfaces are precision.

Response Microwave
responsemicrowave.com

Capacitors

Passive Plus, Inc. (PPI) now offers extended voltage for the EIA Low ESR 0201N and 0402N. These capacitors now have extended voltage of 50V and 250V respectively, Case sizes are 100% RoHS, and exhibit Low ESR/ESL, Low Noise, High Self-Resonance, as well as ultra-stable performance over temperature.

0201N series: Size: .020" x.010"

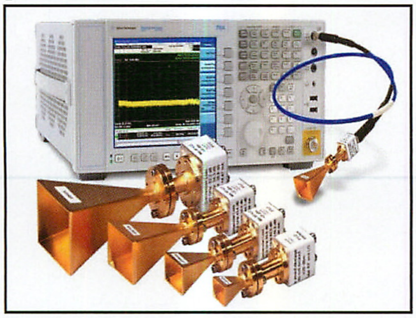
Value Range: 0.1pF – 100pF
WVDC: 25V
Extended WVDC: 50V
Q = 2,000 min. @ 1 MHZ
TC: 0 +/- 30 PPM/°C (-55°C - +175°C)

Passive Plus
passiveplus.com

Spectrum Analyzer Extension Modules

OML can extend the frequency range of your existing spectrum analyzer to millimeter-wave frequencies with our single diode unbalanced harmonic mixers. Harmonic mixers are available for the waveguide bands between 18 and 325 GHz. These frequency extension modules are compatible with most spectrum analyzers that offer optional external mixer access. By substituting the harmonic mixer for the existing microwave input, you can expand your spectrum analyzer frequency coverage for millimeter wave measurements.

Located in the high tech Silicon Valley, the staff at OML are pioneers in microwave and millimeter-wave products. Our test equipment expertise is traceable to the pioneering spirit at Varian Associates (Solid State Microwave Division), which is globally recognized for the innovative design and manufacture of many of the first microwave products.

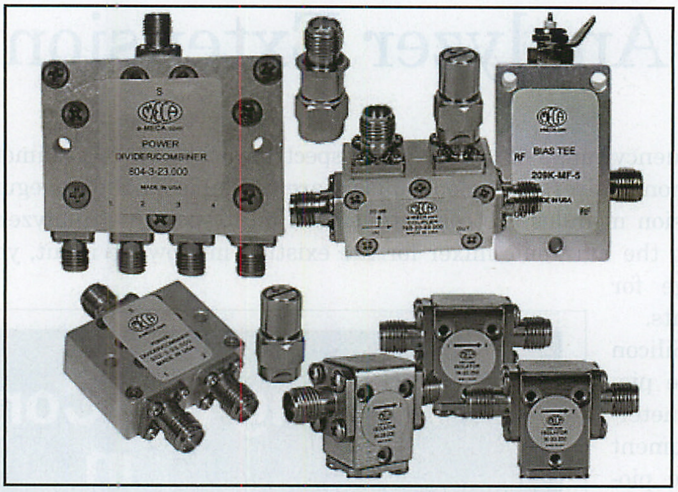


In 1991, Charles Oleson started Oleson Microwave Labs to focus on the specialized needs in the emerging millimeter-wave test equipment market. In 2004, this successful "start up" was incorporated into OML, Inc. where today, as a privately-held company, we continue to evolve as an industry expert and market leader.

Our mission is to be on the innovative forefront of millimeter and sub-millimeter wave technology, while maintaining our role as a solutions partner in the test & measurement field. Our success is sought through collaborative efforts that optimize solutions for price and performance. Offering our customers quick access to service, we strive to build a prosperous millimeter-wave ecosystem together.

OML
omlinc.com

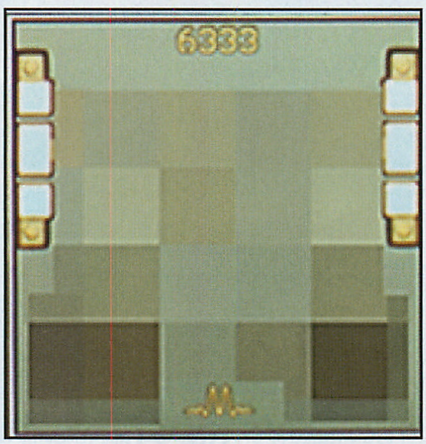
Product Highlights



Millimeter-Wave Products

MECA offers a family of components covering the various proposed bands for 5G and Millimeter-Wave bands. Featuring Power Divider and Couplers covering 6-40 GHz with 2.92 & 2.4 mm interfaces along with supporting components such as Attenuators, Terminations, Bias Tee's, DC blocks and adapters. With octave & mulita-octave units covering 1-18 GHz with SMA interfaces all built by J-Standard certified Assemblers & Technicians.

MECA Electronics
e-meca.com



Equalizer

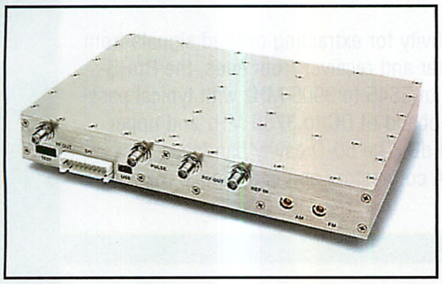
Marki Microwave has expanded its line of passive GaAs MMIC equalizers to cover all applications from L-Band to Ka-Band. The MEQ series equalizers are an ideal solution for compensating for low pass filtering effects in RF/microwave and high speed digital systems. Optimized for excellent return loss over the entire band, the MEQ series equalizers provide consistent unit-to-unit performance in a small low-cost form factor. All MEQ equalizers are available in 1.25mm2 die.

Marki Microwave
markimicrowave.com

Microwave Synthesizers

QuickSyn microwave synthesizers deliver instrument-grade performance, increased functionality, and efficient power consumption at a reduced size and low cost. The synthesizers employ a patented, revolutionary phase-refining technology that provides a unique combination of fast-switching speed and low phase-noise characteristics.

Model FSW-0010 and FSW-0020 cover the frequency ranges of 0.5 to 10 GHz and 0.5 to 20 GHz respectively (extendable down to 0.1 GHz and 0.2 GHz). QuickSyn



synthesizers utilize a fundamental VCO to achieve the desired output frequency. In contrast to frequency multiplication schemes, this approach eliminates possible spectrum con-

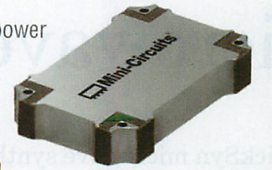
> “QuickSyn synthesizers utilize a fundamental VCO to achieve the desired output frequency.”

tamination from subharmonic products. The use of the advanced direct digital synthesis approach, enables a very fine frequency resolution of 0.001 Hz. The VCO noise is suppressed by utilizing an ultra low noise reference oscillator in conjunction with a low-noise locking mechanism. Microphonic effects are also greatly reduced due to the use of a low-mass VCO and very wide PLL filter bandwidth.

NI Microwave Components
ni-microwavecomponents.com

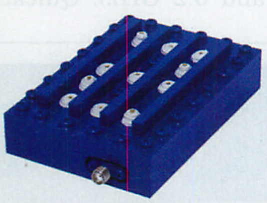
Mini-Circuits PRODUCT SPOTLIGHT

Two-Way 90-deg. Power Splitter Handles 200 W from 2 to 6 GHz



Mini-Circuits' model QCH-63+ is a two-way, 90-deg. power splitter that can handle as much as 200 W input power from 2 to 6 GHz. It maintains excellent amplitude unbalance of ±1.0 dB and phase unbalance of ±1.5 deg. across its wide frequency range, making it ideal for I/Q quadrature systems. The RoHS-compliant, 50-Ω power splitter provides at least 18-dB isolation and typically 26-dB isolation between ports. Insertion loss is low, at typically 0.2 dB, while the VSWR across the full frequency range is typically 1.15:1. The compact power splitter measures 0.56 × 0.35 × 0.091 in. with wrap-around terminations for good solderability, with an operating temperature range of -55 to +105°C.

Cavity Bandpass Filter Screens 3845 to 3905 MHz



Mini-Circuits' ZVBP-3875+ cavity bandpass filter provides high selectivity for extracting desired signals from wide sections of spectrum. Well suited for communications transmitter and receiver front ends, the RoHS-compliant filter features a 3875-MHz center frequency and passband of 3845 to 3905 MHz with typical passband insertion loss of 0.6 dB and VSWR of 1.30:1. It has a lower stopband of DC to 3785 MHz and upper stopband of 3970 to 8500 MHz, both with typical rejection/loss of 43 dB. The 50-Ω cavity bandpass filter measures 3.86 × 2.64 × 0.98 in. (98 × 67 × 25 mm) with female SMA connectors and is designed for operating temperatures from -40 to +85°C.

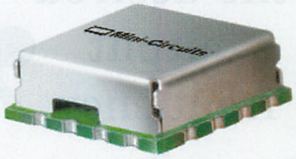
Surface-Mount Bandpass Filter Passes 329 to 335 MHz

Mini-Circuits' BPHI-332+ is a surface-mount bandpass filter ideal for radio communications, defense, and aviation applications. It features a narrow passband of 329 to 335 MHz. Passband insertion loss is no more than 5.0 dB and typically 4.5 dB, while the passband VSWR is no more than 2.0:1 and typically 1.50:1. The RoHS-compliant, 50-Ω filter handles as much as 1.5 W RF input power. Rejection in the lower stopband is at least 40 dB and typically 50 dB from DC to 313 MHz and at least 20 dB and typically 30 dB from 300 to 313 MHz. Rejection in the upper stopband is at least 20 dB and typically 25 dB from 343 to 370 MHz and at least 40 dB and typically 50 dB from 370 to 2600 MHz. The compact filter measures 0.365 × 1.360 × 0.35 in. (9.27 × 34.54 × 8.89 mm in a shielded surface-mount package with an operating temperature range of -40 to +85°C.

2.4-mm Coaxial Termination Handles 1 W to 50 GHz

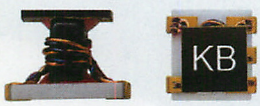
Mini-Circuits' ANNE-50V+ is a 2.4-mm 50-Ω coaxial termination with wide bandwidth of DC to 50 GHz. The RoHS-compliant termination can absorb signal power levels to 1 W across the full frequency range with excellent return loss, typically 28 dB to 18 GHz and 20 dB to 50 GHz. Suitable for measurement laboratories and in defense and aerospace applications, the termination is supplied in a brass case measuring 0.67 in. long and 0.31 in. in diameter with a male 2.4-mm coaxial connector which is mechanically compatible with 2.4-mm and 1.85-mm female connectors. The broadband termination has an operating temperature range of -55 to +100°C.

Surface-Mount Diplexer Separates DC to 2150 MHz



Mini-Circuits' RDP-2150+ is a diplexer that combines low-loss lowpass and highpass filters covering DC to 2150 MHz in a compact, surface-mount 50-Ω package. Well suited for multiband radio and video system applications, the RoHS-compliant diplexer delivers lowpass performance that includes typical insertion loss of 0.5 dB and return loss of 29 dB from DC to 10 MHz. The highpass performance includes typical insertion loss of 0.9 dB and return loss of 16 dB from 40 to 2150 MHz. The lowpass stopband isolation is typically 31 dB from 40 to 2200 MHz and 44 dB from 50 to 2150 MHz, while the highpass stopband isolation is typically 33 dB from DC to 18 GHz and 61 dB from DC to 10 GHz. The diplexer has an operating temperature range of -40 to +85°C and is supplied in a shielded package measuring just 0.500 × 0.500 × 0.180 in. (12.7 × 12.7 × 4.572 mm).

75-Ω RF Transformer Tackles 10 to 1400 MHz



Mini-Circuits' TCM2-142-75X is a compact, 75-Ω surface-mount RF transformer with wide bandwidth of 10 to 1400 MHz. With low typical insertion loss of 1.3 dB and high typical input return loss of 17 dB across the full frequency range, the transformer is suitable for a wide range of transmission-line balancing chores. It handles input power levels to 0.4 W with typical amplitude unbalance of 0.5 dB and typical phase unbalance of 10 deg. The RoHS-compliant transformer measures just 0.15 × 0.15 × 0.15 in. for use in high-density circuits. It features core-and-wire construction and Mini-Circuits' Top Hat® feature for ease of assembly and inspection. It has an operating temperature range of -40 to +85°C.

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How to Make Your Booth a Winner at the Next Trade Show

Tim Burkhard, Associate Publisher, *High Frequency Electronics*

If you've ever walked the floor at a trade show such as the MTT-S, you've no doubt seen the following two types of booths.

The first booth has company reps who are engaging with potential customers. Product demos are underway, literature is being passed out, and questions are being answered. Visitors' badges are being scanned and there is a bowl filling with business cards. This company's show expense is justified, because it is collecting sales leads—the very reason for being at the show. We'll call this Booth A.

The second booth has few or no visitors. A company rep is standing in the booth, clearly searching for the next opportunity to engage someone—anyone at all. You feel sorry for this poor soul, who will likely spend the next three days of his or her life on this fruitless pursuit. The money this company spent on an exhibit has been largely squandered. We'll call this Booth X.

If you have ever been part of Booth X, and want instead to be working in Booth A, here's how.

First, a clarification on terminology. Those engineers who are upstairs in ballrooms attending or presenting technical papers? They are attending a "symposium" or a "conference." They are your customers. Those of us who are instead down on the show floor, representing an exhibiting company in the hopes of drawing those engineers to our booth? We are part of a "trade show," or, more simply, a "show."

Invite people to your party. You would never go to the trouble and expense of arranging for your daughter's wedding, and then fail to send out invitations for the big day. The same applies to your trade-show presence. For a big show such as IMS, you should begin promoting to your target audience months in advance. In fact, there are savvy marketers in this issue of *HFE* that already plan to have their 2018 IMS booth numbers listed in their ads ahead of time. In every press or product release you send out, in every ad or web banner you place—tell people you will be there, and supply your booth number.

Send Your Best and Have a Plan

Send your best people and have a plan. Have you ever visited a booth, only to be turned off by company reps who give perfunctory answers to your questions or seem otherwise engaged? While far rarer now than in the past, this phenomenon still exists.

These types should not be representing your company at the show. Send only people who know your products, who smile, who act like they want to be there. Our industry is blessed with many excellent sales reps—and they always have a plan. They make appointments well in advance of the show. They exhibit excellent time-management skills during the event to maximize sales opportunities. And they engage with customers and prospectives beginning over coffee in the morning, and all the way through dinner or cocktails at night.

"Push" your product or service to the aisle. Wherever possible, don't make people probe deep inside your booth to find out what you are selling. Why does everyone dread walking onto the lot of an automobile dealership? They don't want to be cornered by a pushy salesperson. The same applies here.

If you are showing product, try to configure the booth so that it is as close as possible to the aisle—that is to say, to the customer. When there is a group of people visiting your booth, sometimes your best prospective customer is the quiet one in the rear, listening to others ask questions.

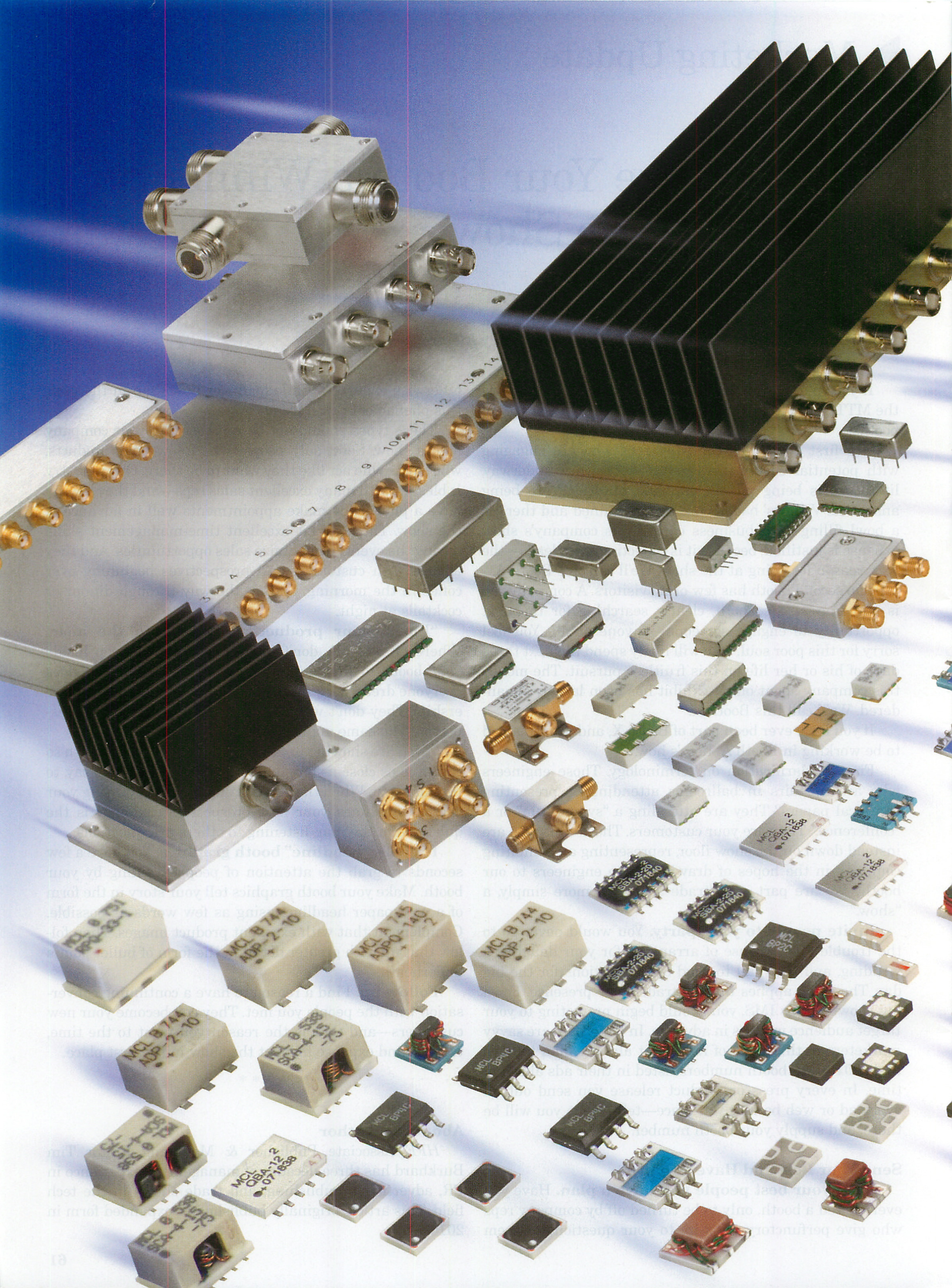
Prepare "headline" booth graphics. You have a few seconds to grab the attention of people walking by your booth. Make your booth graphics tell your story in the form of a newspaper headline, using as few words as possible. Complement that with excellent product images. Then follow that up with greater detail in the form of bullet points underneath.

Follow up. Find a reason to have a continuing conversation with the people you met. They can become your new customers—and that is the reason you went to the time, trouble, and expense to be at the show in the first place.

* * *

About the Author

HFE Associate Publisher & Managing Editor Tim Burkhard has three decades of management experience in PR, advertising, publishing, and trade shows in the tech field. This article originally published in expanded form in 2015.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High Frequency Electronics (USPS 024-316) is published monthly by Summit Technical Media, LLC, 3 Hawk Dr., Bedford, NH 03110.
Vol. 17 No.1 January 2018. Periodicals Postage Paid at Manchester, NH and at additional mailing offices.
POSTMASTER: Send address corrections to High Frequency Electronics, PO Box 10621, Bedford, NH 03110-0621.
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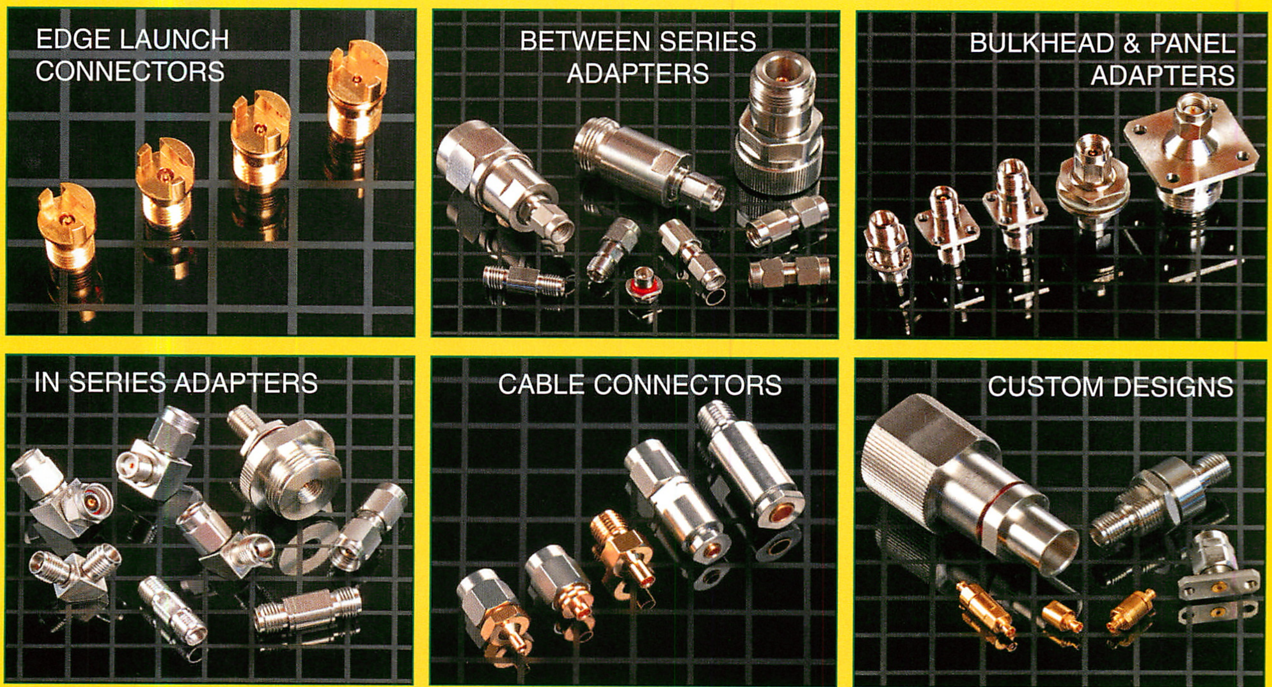

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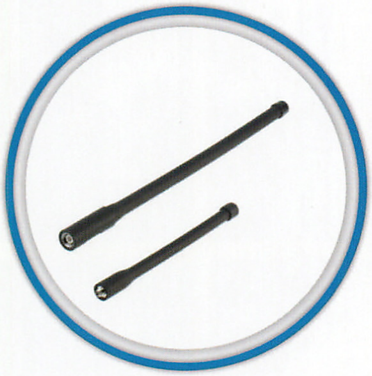

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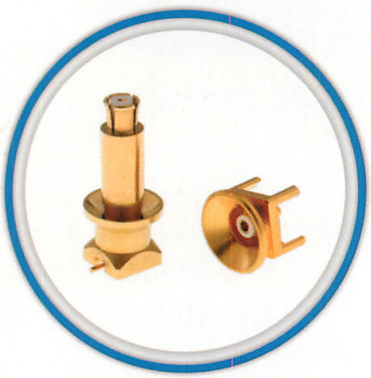

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